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Optimum Engine for Methanol Utilization

Ricardo Consulting Engineers Ltd.
Shoreham-by-Sea (England)

Prepared for

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This report details the work Ricardo Consulting Engineers did in the designing, building and calibrating an engine for methanol utilisation incorporating a Ricardo high compression ratio, compact chamber (HRCC) combustion system. Recommendations for further work are also included.

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RICARDO
CONSULTING ENGINEERS

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OPTIMUM ENGINE FOR METHANOL UTILIZATION

FINAL REPORT

Prepared for

Environmental Protection Agency
Office of Mobile Sources
Emission Control Technology Division
2565 Plymouth Road
Ann Arbor, Michigan 48105

APRIL 1983

RICARDO
CONSULTING ENGINEERS

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SUMMARY

The purpose of this project was to investigate the potential performance of a Ricardo HRCC (high compression ratio, compact chamber) combustion system when fuelled with methanol. The basic engine used for this work was a production 1.5 litre Volkswagen gasoline unit, the combustion system of which was converted to HRCC form with a compression ratio of 13:1.

Baseline tests were made using 98 RON gasoline. The results indicated that engine performance was generally similar to that of other HRCC engines developed by Ricardo; thermal efficiency at part load being approximately 10% better than that of current conventional gasoline engines of similar displacement. The octane requirement was significantly less than that of conventional gasoline engines at the same compression ratio.

The engine was converted to methanol operation by fitting an appropriate carburettor and inlet manifold. Work was then carried out to optimize the performance, especially with respect to fuel economy and exhaust emissions when using this fuel. The ignition distributor was modified to provide automatic spark timing control and an effective EGR system was developed. With the methanol proof carburettor used in this exercise - a relatively simple, single barrel, device - it proved to be impossible to achieve optimum mixture settings over much of the engine's operating range. Despite this, the prototype engine in its final build form was free of detonation and pre-ignition and appeared likely to provide good vehicle driveability, moderately low exhaust emissions and reasonable fuel economy when operated on methanol. Using a computer simulation program the predicted 'engine-out' exhaust emissions and fuel consumption over the 1975 Federal Test Procedure of a 2375 lb passenger car powered by the engine were:

HC - 1.35 g/mile
NOx - 0.98 g/mile
CO - 1.75 g/mile
Fuel Consumption - 14.7 miles/US gallon (methanol)
- 30.3 miles/US gallon (gasoline equivalent)

Considerable improvements in all aspects of engine performance could, most probably, be achieved with the aid of a more sophisticated, twin barrel, carburettor.

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1. INTRODUCTION

In the future, supplies of conventional, petroleum based, fuels for road vehicles are likely to be less readily available and considerably more expensive than at present. The potential of many alternative energy sources to supplement or, in some vehicle applications, to entirely replace conventional fuels has been evaluated by numerous investigators and the relative merits of many of the possible alternative fuels are now quite well understood. Methanol has various characteristics which are desirable attributes of future alternative fuels - it can be produced from a variety of raw materials (some of which are renewable), production technology already exists, the fuel is in liquid form which facilitates storage, transportation and handling and its energy density is moderately high which provides an extensive vehicle range for a quite modest weight of fuel.

Of the properties of methanol which specifically relate to its suitability as a fuel for conventional light duty engines, its poor self ignition characteristics - low cetane number - ensures that it cannot be easily utilised in diesel units. Conversely its high octane quality implies fairly ready application in spark ignited engines. The octane number of methanol is significantly higher than that of current motor gasoline so that it lends itself for use in engines having relatively high compression ratios with inherent thermal efficiency advantages over current gasoline engines. Methanol also has good lean burn properties, so offering further advantages in terms of thermal efficiency and low exhaust emissions when employed in a spark ignited engine.

In recent years several research organisations have worked on the development of engine concepts capable of successfully utilising high compression ratios. The Ricardo HRCC (high compression ratio, compact combustion chamber) engine is one example of this approach which by careful design of the combustion chamber permits the use of a high compression ratio (with a relatively low fuel octane requirement) together with an ability to successfully utilise lean mixtures or tolerate high levels of EGR - important attributes with regard to both fuel economy and exhaust emissions.

Considerations of the major performance characteristics of the HRCC combustion system and some of the properties of methanol fuel (high octane quality and good lean burn characteristics) suggested that they complemented each other to a large extent. It therefore appeared that an HRCC unit was a promising basis for the development of an optimum engine for methanol utilisation. In order to confirm this theory a practical engine test programme aimed at investigating the potential performance, fuel economy and exhaust emissions of an HRCC engine when fuelled with methanol was considered, by EPA, to be necessary. As originally envisaged this project was to involve work by Ricardo in four main stages:-

i) Production of an HRCC engine based on a standard Volkswagen gasoline unit.

ii) Test bed development of the HRCC engine, including modification and appraisal of any components or systems necessary for successful methanol utilisation.

iii) Installation of the developed engine in a passenger car, together with necessary modifications to the vehicle's fuel system to permit methanol fuelling.

iv) Final calibration of engine fuelling, ignition timing and scheduling of any necessary emission control systems in order to produce an engine build fully optimised for methanol utilisation and meeting target exhaust emission levels over the 1975 Federal Test Procedure of 0.2/1.8/0.8 g/mile HC/CO/NOx respectively.

Due to budget cutbacks within EPA the contract eventually awarded to Ricardo covered only the first two stages of the total work programme outlined above, vehicle installation and final engine calibration, including provision of an exhaust oxidation catalyst would be performed, 'in-house' by EPA.

2. THE HRCC ENGINE

2.1 General

The Ricardo HRCC gasoline combustion system has been the subject of considerable research and development work over a number of years (1-5)*. This work culminated in the derivation of general guidelines for the design of combustion chambers capable of operating at compression ratios of 1 to 2.5 numbers higher than conventional combustion chambers, when using fuel of equal octane quality, resulting in economy improvements of the order of 5%. The HRCC arrangement was also found to permit utilisation of leaner air/fuel mixtures than was possible with conventional combustion chambers while still maintaining an adequate safety margin from the misfire limit and consequent vehicle driveability problems; this yielded further fuel economy improvements, making a total of the order of 10%. Furthermore it was found that increases in brake mean effective pressure (BMEP) of 5-10% over much of the engine's speed range were generally achieved with HRCC combustion systems.

The ability of HRCC engines to operate well with lean air/fuel mixtures ensured that NOx and CO emissions were relatively low. HC emissions were somewhat increased over those produced by well developed conventional

*Numbers in parentheses indicate references listed in section 9.

combustion chambers operating at a lower compression ratio but were nevertheless maintained at a reasonable level.

Most of the initial HRCC investigations were carried out using single cylinder research engines. Later the experience gained with the single cylinder units was applied in a Ricardo research exercise to the design of an HRCC version of a production 1.5L, four cylinder, Volkswagen engine. After a short development programme this engine was installed in a passenger car in which application it exhibited good performance, fuel economy and exhaust emission characteristics when operating on 97 RON gasoline (6).

As a basis for the production of an optimum engine for methanol utilisation a unit identical to the original HRCC version of the 1.5L Volkswagen engine used in Ricardo's research work was employed.

2.2 Engine Characteristics

The basic Volkswagen engine used in this exercise had the following main characteristics.

Cylinders	4, in-line
Bore Diameter	79.5 mm
Stroke	73.4 mm
Displacement	1.457 litres
Compression Ratio	8.2:1
Cylinder Block	cast iron with integral cylinder bores
Cylinder Head	aluminium with uni-sided inlet and exhaust ports
Combustion Chambers	bath tub type in cylinder head
Valve Gear	1 inlet and 1 exhaust per cylinder, vertically in-line, driven directly by an overhead camshaft
Inlet Valve Inner Seat Dia	30.5 mm
Exhaust Valve Inner Seat Dia	29.5 mm
Carburettor	Twin barrel Zenith type 2B5
Ignition System	conventional coil with mechanically driven distributor having speed and load advance

In order to convert the engine to HRCC form, several new components were required. Of these the major item was the cylinder head which incorporated the HRCC combustion chambers. The main features of the combustion chamber are indicated on Fig. 1, it was of compact design and was situated under the exhaust valve, its aspect ratio - maximum length divided by its depth - was 3.8. The introduction of the HRCC combustion system involved some changes to other features of the cylinder head compared to those of the production unit. Spark plug location was slightly different and the vertical positions of the inlet and exhaust valves were changed.

Lowering the inlet valves permitted introduction of revised inlet ports, as shown on Fig. 2, which had better flow characteristics than did the inlet ports in the production cylinder head. Most of the external features of the cylinder head, including the disposition of manifold mounting flanges and the location of the camshaft, were identical to those of the production unit. A photograph of the lower face of the cylinder head is shown in Fig. 3.

Modified pistons were fitted to the HRCC engine, These were of basically similar design to the production components, having flat crowns, but the compression height was increased to give a nominal piston/head clearance of 1% of the stroke and the disposition of the rings was changed in order to reduce the height of the top land and increase the height of the second land. With the revised cylinder head and pistons the engine's compression ratio was 13:1.

A camshaft producing valve events differing from those of the production unit was fitted to the HRCC engine. Experience with the similar, gasoline fuelled, Ricardo research engine had indicated that the revised camshaft produced higher BMEP at low speeds than the production unit without compromising other aspects of performance. The valve events provided by this camshaft were:-

	Inlet	Exhaust
Valve Opens	8° BTDC	51° BBDC
Closes	52° ABDC	9° ATDC
Maximum Lift	9.3 mm	9.3 mm

EPA had requested that a Delco-Remy high energy ignition system be fitted to the engine. This employed an integral coil/distributor unit of rather large dimensions which was impossible to fit directly in the place of the standard Bosch distributor located on the side of the cylinder block. The original distributor drive was therefore extended upwards to the Delco-Remy unit which was positioned alongside the top of the cylinder head. In order to avoid possible problems of seizure of the bearings in the distributor drive line a small oil reservoir providing a drip feed was incorporated.

In order to achieve the target HC and CO emission levels of 0.2 and 1.8 g/mile respectively over the LA4 test cycle it was recognised that it would be necessary during the final vehicle calibration to employ an exhaust oxidation catalyst and secondary air system. In order to facilitate this a production Volkswagen air pump, driven from the nose of the crankshaft by a vee belt, was installed on the engine. These modifications (head, pistons, camshaft, distributor) were used for all testing of the engine that is reported in this document.

For initial testwork, during which gasoline fuel was employed, the HRCC engine was fitted with the production inlet manifold and twin barrel carburettor. The latter had fuel and air metering jets, etc, which had been found during development of the Ricardo research HRCC engine to provide optimum performance. For testwork with methanol fuel a prototype inlet manifold, supplied by Volkswagen, was used. Its internal shape was very similar to that of the production gasoline unit but it incorporated a more extensive engine coolant jacket in order to provide increased charge heating to offset the relatively high latent heat of vaporisation of the methanol. A prototype single barrel, Solex carburettor Type 34 PIC (T)5 was employed when operating with methanol, this had a special, methanol proof, phosphate coating on all of its surfaces to prevent chemical attack by the fuel. It was anticipated that difficulties would be encountered in obtaining optimum fuel/air mixture strength modulation over the engine's operating range when using this relatively unsophisticated carburettor. Unfortunately, at the outset of the project, this was the only methanol proof unit available. A production Volkswagen air cleaner of 'pancake' form, directly mounted on the carburettor was used.

A production exhaust manifold of 4 into 2 form was fitted to the engine. For all testwork conducted by Ricardo production twin exhaust downpipes approximately 0.5 m long coupled to a large bore test shop exhaust system were employed.

During development a simple EGR system incorporating a conventional vacuum operated flow control valve (Pierburg part no. 73195A) was fitted.

3. CHARACTERISTICS OF METHANOL FUEL

Several of the properties of methanol are particularly noteworthy regarding its use as a fuel for spark ignited engines. It has a high knock resistance; several different values of RON and MON are quoted in the literature, the variation being mainly due to the difficulties involved in applying a test procedure developed for use with relatively low octane, wide boiling range, gasolines to high octane, single boiling point, methanol which has a high latent heat of vaporisation. The high knock resistance favours the use of high compression ratios.

A very significant adverse property of methanol, which affects its use in engines, is its strong tendency to pre-ignite (7). Many earlier investigations of methanol utilisation have encountered this problem. It can be alleviated by attention to cooling of combustion chambers and by employing an appropriate grade of spark plug, but has been found to be a troublesome feature in some engine application exercises.

The calorific value on a weight basis of methanol is only 45% of that of gasoline hence a considerably higher fuel flow is required at any given engine operating condition. This implies the need for changes in the fuel metering system where changing from gasoline to methanol operation.

The density of methanol is higher than that of gasoline hence fuel consumption on a volumetric basis is not as high as might be anticipated by consideration only of its calorific value.

The high boiling point of methanol together with its high latent heat of vaporisation are responsible for the poor cold starting characteristics often associated with engines using this fuel. The most popular means of overcoming this problem, cited in the literature, is by using either a fuel additive which has a low boiling point, e.g. isopentane (8), or a supplementary fuel, such as conventional gasoline, which is used only for starting (9). Both of these approaches involve significant inconvenience and/or complexity. A more desirable approach is the use of supplementary heat applied to the ingoing charge which may assist charge vaporisation and obviate the formation of ice in the intake system during conditions of high ambient humidity.

Methanol has generally wider mixture strength combustion limits than gasoline. This is largely due to the higher flame speeds which occur in methanol/air mixtures (10). In conventional engines with fairly low compression ratios the ability to operate with a leaner mixture strength can produce some advantages in terms of fuel economy and regulated exhaust emissions, particularly of NOx and CO.

Combustion temperatures of methanol/air mixtures are significantly lower than those occurring in gasoline/air mixtures even when initial mixture temperatures are equal (11). In practice the high latent heat of vaporisation of methanol ensures that the temperature after compression of a methanol/air mixture is considerably lower than that of an equivalent gasoline/air mixture. Lower combustion temperatures favour lower heat losses, hence producing higher thermal efficiency, and also inhibit the production of NOx during the combustion process.

Combustion of methanol produces a greater number of moles of combustion products than is the case with gasoline. The combustion equations for stoichiometric air/fuel mixtures of the fuels are as follows:

For a typical gasoline -

$$CH_{1.8} + 1.45\ (O_2 + 3.77\ N_2) \rightarrow CO_2 + 0.9\ H_2O + 1.45\ (3.77\ N_2)$$

i.e. for every 6.92 moles of air consumed 7.37 moles of products are formed, a ratio of 1.065.

For methanol -

$$CH_4O + 1.5\ (O_2 + 3.77\ N_2) \rightarrow CO_2 + 2H_2O + 1.5\ (3.77\ N_2)$$

i.e. for every 7.16 moles of air consumed 8.66 moles of product are formed, a ratio of 1.209.

The greater number of moles of product from methanol combustion favours the production of a higher pressure in the cylinder, hence a greater engine power output and the attainment of a higher thermal efficiency.

Methanol can chemically attack some of the materials commonly used in engine fuel systems, notably the magnesium alloys often used in carburettors. Such corrosion is a particular problem when water is also present. Some polymers often used as sealing materials may also suffer chemical degradation or be liable to swelling when in contact with methanol.

4. TEST EQUIPMENT AND DATA ANALYSIS

4.1 Test Bed Installation and Instrumentation

The engine was installed on a test bed and coupled to a Heenan and Froude Mark I Dynamatic dynamometer (eddy current type). Instrumentation was provided for the control and monitoring of lubricating oil and cooling water temperatures; these were regulated to 80°C oil inlet/water outlet. Inlet air temperature was measured at the carburettor inlet, hence for tests where an air cleaner with temperature control was used the inlet temperature was measured downstream of hot/cold air entry points. Exhaust gas temperature was measured at a point about 200 mm downstream of the junction of the twin downpipes. A gas sample probe was fitted at the same location. Inlet manifold pressure was measured using an accurately calibrated conventional pressure gauge (Bourdon tube type). Exhaust back pressure was determined using a mercury manometer. Fuel flow was measured with a Cussons gravimetric flow meter. Ignition timing was varied by means of a linkage which permitted remote adjustment of the angular orientation of the ignition unit; the resulting timing was measured with a Cussons ignition timing meter. Variations in air/fuel mixture strength were produced by changes to carburettor jets and by use of a Ricardo suck/blow device which varied the pressure in the carburettor float chamber.

Samples of exhaust gas were analysed using Ricardo emissions trolleys. During initial testwork using gasoline fuel the analysers employed were:-

CO, CO_2, NO - Analytical Developments NDIR
HC - Analysis Automation FID
O_2 - Servomex paramagnetic type OA250

For engine operation on methanol another emissions trolley was employed, this had the following analysers:-

CO, CO_2 - Analytical Developments NDIR
NOx - Thermoelectron Corp. Model 10 Chemiluminescent Analyser
HC - Ratfisch RS5 FID fitted with a separate, heated, (120°C) sample line
O_2 - Servomex paramagnetic type OA250

The FID analysers used for HC measurements were calibrated using propane. All HC measurements were then converted to a base of ppm carbon before calculation of brake specific HC emissions. The brake specific HC emissions were therefore directly comparable when operating with both gasoline and methanol fuels although the low response (40%) of the FID to methanol ensured that when this fuel was employed a significant proportion of the total unburnt fuel emissions was not recorded. Towards the end of the project some measurements were made of aldehyde emissions produced by the engine when operating on methanol. For this work a sample of the exhaust gas, drawn from the heated sample line was bubbled through two bottles of pure methanol connected in series. The quantity of aldehydes absorbed by the methanol (measured as formaldehyde) was determined by the DNPH method (12).

4.2 Test Fuels

Most of Ricardo's previous work with HRCC engines has been conducted using standard European 'super' gasoline, e.g. BS4040 'four star' fuel, having a minimum RON of 97. In order to ensure that the HRCC engine used in the present exercise had broadly similar performance characteristics to those of earlier examples of the engine some initial performance tests were made using this gasoline fuel. Relevant fuel inspection data are given in Table 1. The specification and other relevant data of the methanol fuel used during this exercise are shown in Table 2.

4.3 General Data Processing

Raw test bed data were processed using a Ricardo 'in-house' computer program. This provided correction of full load performance measurements to 20°C, 760 mm Hg using the method described in DIN 70020. Brake specific fuel consumptions and exhaust emissions were also calculated; $BSNO_x$ results were corrected to 75 grains/lb humidity using the EPA correction formula. In order to facilitate comparison of data brake specific fuel consumptions, when gasoline and methanol fuelled, were converted to brake thermal efficiencies by using the appropriate calorific values of the fuels noted in Tables 1 and 2.

Mixture strength air/fuel ratio, and hence equivalence ratio, was calculated from emissions data using the Spindt-equation (13) in the case of gasoline fuelling. With methanol fuelling a method derived by Brettschneider (14) was employed.

Volumetric efficiency and brake specific air consumption were determined from measured fuel flows and the calculated air/fuel ratios.

Equivalence ratio defined as:- $\dfrac{\text{stoichiometric air/fuel ratio}}{\text{actual air/fuel ratio}}$

was used when considering all results in order to facilitate comparison of engine performance when operating with gasoline and methanol since these fuels had widely different stoichiometric air/fuel ratios.

EGR rate was defined as the flow rate of recycled exhaust gas divided by the total flow rate into the engine and was calculated as follows:-

$$\% \text{ EGR} = \frac{\text{Inlet } CO_2 \text{ with EGR} - \text{Inlet } CO_2 \text{ without EGR}}{\text{Exhaust } CO_2 \text{ with EGR}} \times 100$$

4.4 Vehicle Simulation Work

Since the ultimate objective of the project was to produce a methanol fuelled engine capable of providing good vehicle performance it was considered important to assess the likely fuel economy and exhaust emissions of a vehicle fitted with the engine. In order to provide approximate predictions of these characteristics a Ricardo computer simulation program (15) was employed.

The computer program used (CYSIM) is primarily designed to predict the levels of exhaust emissions and fuel consumption to be expected from a vehicle during operation over a prescribed velocity cycle (in this case the 1975 FTP). Vehicle performance, in terms of acceleration times, can also be predicted.

Essentially the program analyses the driving cycle and, from a knowledge of vehicle characteristics, calculates the engine speed and BMEP required to drive the vehicle over each velocity increment in turn. Knowing these two parameters the levels of exhaust emissions and fuel consumption are extracted from engine test bed performance maps which are represented in the program input data by two dimensional numerical arrays.

The emissions data used as input to the simulation program and hence the predicted results produced by it referred to 'engine-out' exhaust conditions.

The effects of any exhaust after treatment system, such as the oxidation catalyst which was fitted to the engine exhaust system during the later vehicle application tests to be conducted by EPA, were ignored.

It should be emphasised that the predicted results produced by the simulation program are very approximate due to the use of several simplifying assumptions which are incorporated in the program in order to facilitate its use. The principal sources of errors are:-

i) The computer program produces simulated results of transient tests using engine performance and emissions data derived under steady state conditions, it is likely that under true transient operation engine performance and emissions levels will show some variation from predicted results.

ii) All engine data used as input is nominally acquired at normal operating temperatures. In actual 1975 FTP tests, the engine starts from cold and hence its performance and emissions during the early part of the test may be considerably different to what is predicted.

(These two points have been confirmed in previous work in which simulation results were compared with measured data when some divergence, especially in the case of HC emissions, has been observed).

It had been observed in previous exercises that the computer predicted values of HC and CO emissions were generally lower than those observed during actual vehicle tests, primarily due to the fact that the effects of cold start mixture enrichment and the enrichment normally occurring during transient manoeuvres in a real vehicle installation are ignored in the simulation program.

For the vehicle simulation exercises the engine was assumed to be installed in a Volkswagen Jetta passenger car. The main characteristics of this vehicle were taken as:-

Weight	1020			
Transmission	manual, 4 speed			
Ratios	1	2	3	4
	3.45	1.94	1.29	0.97
Final Drive Ratio	3.9			
Tyre rolling radius	0.26 m			
Polar moment of inertia of:				
engine and gearbox	0.18 $Kg.m^2$			
driving wheels	1.81 $Kg.m^2$			

Inertia weight and road load settings specified in the Federal Register (vol. 42, no. 124, 28th June 1977) for a passenger car weighing 1020 Kg were used.

5. ENGINE DEVELOPMENT

5.1 Baseline Tests with Gasoline

Ricardo have considerable previous experience of operating a 1.5 litre HRCC version of the Volkswagen engine on 97 RON gasoline. It was therefore decided to first carry out some baseline performance tests on the EPA HRCC engine using this gasoline fuel and with the same engine build as had been employed in previous exercises. Comparison of the results of these tests with those obtained from previous engines would provide assurance that the performance of the EPA engine was typical of other HRCC units; the results would also provide a baseline from which the performance exhibited when methanol fuelled could be assessed. For these tests the engine was therefore fitted with a production inlet manifold and twin barrel carburettor having chokes, metering jets, etc. which had been found previously to provide good full load performance throughout the speed range.

After an initial 20 hour break-in period during which speed and load were progressively increased the engine was operated at a variety of speeds and loads for approximately 30 hours in an attempt to achieve stable engine friction levels and a representative level of combustion chamber deposits. Following this the full load performance was measured over the speed range from 20 to 90 rev/s.

The results produced by the engine in this build are plotted on Figs. 4-6; also shown, for comparison, are the results of an earlier test made on a similar HRCC engine with identical operating conditions. (The data used to plot these and subsequent graphs is given in tabular form in the Appendix to this report). A moderately high level of BMEP was achieved throughout the speed range, this could be largely attributed to the excellent volumetric efficiency of the engine brought about by the use of free-flowing inlet ports, the absence of an air cleaner and the presence of a negligible level of exhaust back pressure. The engine performance compared quite well in most respects to that of the previously tested HRCC engine. The BMEP was a little higher throughout the speed range than had been previously observed but the shape of the curve was almost identical. At low-mid speeds the increase in BMEP was probably caused by the higher volumetric efficiency which in turn may have been caused by slight differences in inlet port shape, valve timings, etc. between the two nominally identical engines. The mixture strength supplied by the carburettor was generally a little leaner than had been observed in the previous exercise, at 30 rev/s the carburettor produced an over-rich mixture probably due to peculiar pressure pulsations within the intake system at that particular speed.

Ignition timings of the two engines were quite similar, the timings of the EPA engine being a little less advanced at all speeds above 20 rev/s. With both engines MBT (minimum advance for best torque) timings were used where possible. Despite the use of 98 RON gasoline both engines were knock limited over much of the speed range. The difference in knock limited ignition advance between the two engines was partly due to the differences in mixture strength, richer mixtures producing greater internal engine cooling and so enabling more advance before knock was encountered, this trade-off is well illustrated by the mixture strength/ignition timing results at 30 rev/s (fig. 6).

The exhaust temperatures of the two engines differed by about 100°C. This can be explained by the differences in engine output and mixture strength and by the fact that the thermocouples used to measure the temperatures were in slightly different positions in each case.

In order to obtain an indication of the octane requirement of the engine some tests were made at full load at 30, 40 and 50 rev/s using both the 98 RON gasoline employed for the power curve test and using 105 RON avgas. With both fuels the mixture strengths used were those supplied 'automatically' by the carburettor. Knock limited spark advance was determined with both fuels, and, with avgas, the MBT timing was also identified. The results are plotted on fig. 7 and indicate that the engine's fuel octane requirement was circa 100-101 RON for the particular test conditions, mixture strengths and fuels used. A broadly similar octane requirement has been demonstrated by other HRCC engine under similar circumstances. It should be noted that other work conducted by Ricardo had indicated that when using avgas in HRCC engines MBT timings are generally some 2^{o} more advanced than those required when using motor gasoline. This discrepancy may be attributable to the different formulation of the two fuels.

Baseline tests using gasoline were also run at four selected speed/load conditions -

20 rev/s, 1.5 bar BMEP
40 rev/s, 2.5 bar BMEP
40 rev/s, 5.5 bar BMEP
60 rev/s, 4.0 bar BMEP

These conditions are frequently used by Ricardo as test points since they cover the speed/load range commonly used by engines in light duty vehicles. At each test condition the mixture strength was varied in stages from rich of stoichiometric to the lean limit of stable running. The results of these tests together with the results of similar tests run previously on the identical Ricardo research HRCC engine are plotted on Figs. 8-19.

The results produced by the two engines were broadly similar. At all test conditions the optimum brake thermal efficiency produced by both engines differed by a maximum of 0.7% in absolute terms or about 4% in relative terms. These differences can be accounted for by probable small variations in the engine builds e.g. in combustion chamber configurations, valve events, inlet and exhaust tract configurations, bearing friction levels, etc. It was apparent that the EPA engine produced maximum thermal efficiency at mixture strengths somewhat leaner than those observed with the Ricardo research engine. The lean limit of operation of the EPA engine was also at rather lower equivalence ratios (.59 or 24.7:1 air/fuel ratio at 40 rev/s, 2.5 bar and 60 rev/s, 4.0 bar). This extension of the lean limit may have been due to small differences in in-cylinder turbulence levels caused by small changes in valve events, squish clearances etc. or by addition of the high energy Delco ignition system.

The exhaust emissions of the EPA engine also showed some differences. HC emissions were generally slightly higher than those produced by the

Ricardo research engine. Again this may have been partly due to small differences in in-cylinder combustion conditions but the main cause was probably differences in exhaust sampling position which permitted less oxidation of the exhaust gases in the time between their leaving the cylinder and reaching the sample point. At 20 rev/s, 1.5 bar NOx emissions were considerably higher from the EPA engine and displayed a different variation with mixture strength to that observed on the earlier engine. The cause of this was most probably particularly poor cylinder to cylinder mixture distribution at this operating condition; this possibility was not investigated since the object of the project was to develop a methanol burning engine and not to perfect operation on gasoline.

5.2 Conversion to Methanol Operation

Following completion of the baseline tests with gasoline the engine was converted to methanol build by fitting the appropriate intake manifold and carburettor. As noted earlier the intake manifold was of very similar form to the production gasoline unit but had a more extensive engine coolant jacket in order to add more heat to the fuel/air charge and therefore offset the effects of methanol's relatively high latent heat of vaporisation. The methanol carburettor was a relatively simple single barrel device having a protective phosphate coating on all surfaces liable to come into contact with the fuel.

Initial tests using methanol were conducted with a thin (6 mm) adaptor plate interposed between the carburettor and inlet manifold. The plate was necessary since the opening into the manifold was of dimensions suitable for the mounting of a twin barrel Solex carburettor while the carburettor used (the only methanol proof unit available) was of single barrel configuration. No air cleaner was employed during initial tests.

5.3 Full Load Performance

In order to assess the potential maximum performance of the engine when methanol fuelled a full load test over the speed range was conducted using optimised mixture strengths and ignition timings. The results are plotted on Figs. 20-22 and may be compared with the results obtained with gasoline shown on Figs. 4-6.

BMEP was generally higher at low speeds and lower at high speeds than was obtained with gasoline operation. Volumetric efficiency, with the single choke carburettor, was rather low throughout the speed range and was primarily responsible for the reduction in BMEP at high speeds. The engine was knock free throughout the speed range; the ability to utilise MBT ignition timings was mainly responsible for the relatively high BMEP achieved at low-mid speeds. The reduction in BMEP at 20 rev/s relative to that obtained with gasoline was probably mainly due to the especially poor cylinder to cylinder mixture distribution at this condition (see later section 5.6 and Fig. 38). The differences in engine operating parameters, e.g. volumetric efficiency levels and the use of MBT compared with knock limited spark advance, conspired to ensure that the theoretical gain in torque which might be anticipated when changing to methanol fuel (due to the increased number of moles of combustion products - see section 3) was not really obvious. Also the changes to the inlet system - different carburettor and manifold tended to mask any gains in volumetric efficiency which might have been caused by the charge cooling effects of the methanol due to its high latent heat of vaporisation.

The achievement of MBT ignition timings even at low speeds reflected the good anti-knock properties of methanol and the relatively modest octane requirement of the HRCC combustion system even when operating at a compression ratio of 13:1. The MBT timings with methanol at 30, 40 and 50 rev/s were 12, 15 and 18° BTDC respectively, these timings were 3° less advanced than the MBT timings determined using avgas. Due to differences in volumetric efficiency and mixture strength the full load ignition advance requirements cannot be compared on a truly equivalent basis but this and later part load results suggest that slightly less ignition advance was required with methanol fuel than when using gasoline, reflecting the reduced ignition delay and faster flame speed associated with this fuel.

The mixture strength at which best torque was obtained was generally richer when using methanol than in the case of gasoline. This difference can be largely attributed to the very poor cylinder to cylinder mixture distribution produced by the methanol carburettor/inlet manifold.

Exhaust gas temperatures were lower when running on methanol. This was a reflection of the generally lower combustion cycle temperatures caused by the fact that the calorific value of methanol is less than half that of gasoline and its latent heat of vaporisation is very much higher. Hence twice as much fuel having considerably greater cooling potential was employed in the case of methanol.

Over most of the speed range the engine's full load brake thermal efficiency when either methanol or gasoline fuelled was approximately equal at 28%. A somewhat higher thermal efficiency was achieved at 40 rev/s in both cases due to the fact that a relatively lean mixture strength produced best torque at this particular speed.

The brake specific air consumption (BSAC) when methanol fuelled was very low - circa 3.4 Kg/kWH over much of the speed range. This was primarily due to the achievement of good combustion efficiency which in turn was brought about by the relatively low temperature combustion of methanol/air mixtures. The low temperature implied less heat losses to the combustion chamber walls, less dissociation and a more favourable ratio of specific heats of the combustion products.

5.4 Knock and Pre-ignition Characteristics

The full load tests described earlier had indicated that when employing the mixture strengths necessary for the production of maximum torque at full load (WOT) the engine was knock free and MBT ignition timings could be safely employed. It was considered desirable to establish the safety margin available between the knock limited and MBT ignition timings throughout the speed range. Also, since methanol was known to have a strong tendency to pre-ignite it was considered essential to make some investigations of the pre-ignition characteristics of the engine when operating on this fuel.

In order to determine the onset of pre-ignition an established Ricardo technique was employed, a similar approach was also used in other work with alcohol fuels reported elsewhere (17). Essentially the spark plugs in each cylinder were simultaneously employed in their normal role as sources of ignition and also as ionisation gaps to indicate the passage of a flame front. To do this the electrical circuit illustrated in Fig. 23 was attached to each plug and output traces from each circuit were displayed on an oscilloscope. Examples of the oscilloscope traces observed in various modes of engine operation are shown on Fig. 24. Due to the use of a high energy ignition system on the engine considerable interference between the pre-ignition detection circuits was encountered, but extensive shielding of the ignition system and careful interpretation of the oscilloscope traces by the test operator enabled meaningful results to be obtained.

The major results of this exercise are indicated on Fig. 25. Using Champion BN60Y spark plugs - the coldest grade readily available of the type which would fit the engine - ignition timings at least 10° more advanced than MBT could be safety employed over most of the speed range. At 80 and 90 rev/s stable autoignition was observed in no. 3 cylinder at quite advanced timings - this appeared as virtually simultaneous ignition of the cylinder charge by the hot insulator around the plug centre electrode and by the normal spark. Unlike the case of true pre-ignition the timing of autoignition did not advance during successive engine cycles. Changing to a less cold plug grade - Champion BN6Y - resulted in violent pre-ignition occurring in numbers 2 and 3 cylinders at speeds of 50 rev/s and greater with very little advance of ignition timing beyond MBT. Inspection of the engine components after the incidence of pre-ignition revealed that the ceramic insulators around the spark plug centre electrodes were damaged, suggestingthat pre-ignition was initiated at these points.

It was generally concluded from this work that when fitted with a suitable grade of spark plugs and operated with an appropriate mixture strength neither knock nor pre-ignition was likely to occur in the HRCC engine when using methanol fuel.

5.5 Part Load Mixture Loops

In order to provide a broad assessment of the performance of the engine/fuel combination, at the operating conditions commonly encountered in a vehicle application, tests were made at the same part load conditions as had been used with gasoline fuelling. The results are plotted on Figs. 26-37 together with the results of the earlier tests when gasoline fuelled.

At three of the part load conditions methanol operation produced relative gains in maximum brake thermal efficiency of 4-6% over the results with gasoline fuel. These gains could be attributed to the effects of lower combustion temperatures when using methanol and the greater number of moles of combustion products per mole of fuel. At 40 rev/s, 2.5 bar there was very little difference in maximum thermal efficiency, there was no obvious explanation for such a result at this test condition.

Particularly at the lower speed and load test condition, there was a tendency for maximum thermal efficiency to occur at leaner mixture strengths with methanol than with gasoline fuelling. At 20 rev/s, 1.5 bar there was a marked extension of the lean limit of stable operation when using methanol. Both of these trends were probably attributable to the higher flame speeds normally associated with methanol combustion, this would permit relatively good combustion with leaner mixtures where thermal efficiency improvements should result.

NOx emissions were considerable lower (by about 60%) at any specific speed/load/mixture strength condition than when gasoline fuelled. This phenomenon was directly attributable to the lower combustion temperatures which occurred when running on methanol, a fact confirmed by the considerably lower exhaust gas temperatures in this case.

HC emissions, measured by a FID analyser equipped with a heated sample line, were approximately half the level produced during gasoline operation. The FID analyser was, of course, rather insensitive to emissions of methanol (40% response) so that unlike in the case of gasoline operation total unburnt fuel emissions were not directly recorded. Some tests were made using an unheated sample line to the FID. In these circumstances most of the methanol in the exhaust stream was condensed in the sample line and did not reach the FID. These tests produced HC emission measurements some 40% lower than those obtained when using a heated sample line. It could be concluded from this that the true total HC plus unburnt fuel emissions were approximately 1.6 times the levels calculated directly from the FID readings.

All HC results in this report are based on FID measurements. No correction factors are included for the FID response to methanol.

It was observed that, when methanol fuelled, HC emissions increased gradually with mixture strengths leaner than about 0.9 equivalence ratio whereas when gasoline fuelled the general level of HC emissions remained approximately constant until the lean limit of operation was quite closely approached, when the emissions increased rapidly. This sudden, rapid, increase commonly observed in gasoline engines can be accounted for by the occurrence, with lean mixtures, of only partial combustion in the engine's cylinders, the flame front being generally rather weak and slow moving and quenching of the flame occurring before all the charge is consumed. The gradual increase of HC emissions, even with fairly rich mixtures, when methanol fuelled may have been caused by the low temperatures associated with methanol combustion; these low temperatures probably produced larger quantities of unburnt or partly burnt gas at the relatively cold surfaces of the combustion chamber.

The ignition timing requirement when operating on methanol was generally slightly less advanced than that for gasoline operation. Published work (10, 16) based on other methanol utilisation exercises also notes a similar trend but generally of a greater magnitude than the 2-3^{o} difference observed in the present exercise. The reduced ignition advance can be accounted for by the shorter ignition delay period and more rapid flame speeds in methanol/air mixtures. In the HRCC engine the high compression ratio and high level of in-cylinder turbulence ensures that even with gasoline fuelling the combustion period is shorter and ignition advance requirement is considerable less than in a conventional combustion chamber. Hence it could be anticipated that the additional change brought about by methanol fuelling would be relatively small.

5.6 Cylinder to Cylinder Mixture Distribution

In order to assess the cylinder to cylinder mixture distribution of the engine when methanol fuelled, gas sample probes were fitted to the exhaust manifold so that gas in each exhaust port could be sampled. With this arrangement measurements of CO and O_2 concentrations were made at some full load and part load conditions. The results are recorded on Fig. 38.

At full load, mixture distribution was poor with a tendency for the two middle engine cylinders (numbers 2 and 3) to be lean at low and mid speeds. This kind of mixture imbalance is a fairly common phenomenon in four cylinder in-line engines fitted with a single choke carburettor. At part loads mixture distribution between the cylinders was quite uniform.

Since the poor full load mixture distribution did not appear to create significant engine operational problems providing a sufficiently rich overall mixture strength was employed, and since the resources dedicated to this project were limited it was decided to make no direct attempts to improve mixture distribution although observations made later (section 5.15) showed that full load distribution was unwittingly improved as an adjunct to other actions.

5.7 Performance Mapping with Best Economy, Mixture Strength and Ignition Timing

A review of the results of the part load mixture loop tests suggested that operation on methanol at mixture strength equivalence ratios of about 0.7 should produce optimum fuel economy, very low NOx and CO emissions and reasonable levels of HC. It was therefore decided to conduct a mapping exercise over the part load operating range using this mixture strength and optimum ignition timing. The results of this exercise, covering the speed range 20-60 rev/s and BMEP's of 1.5-7.0 bar, are plotted on figs. 39-43.

At the higher loads it was necessary to enrichen the mixture to about 0.8 equivalence ratio in order to obtain the required power output. The brake thermal efficiency of the engine was high; being generally about 10% better in relative terms than previous results obtained by Ricardo from a gasoline fuelled production 1.6l version of the Volkswagen engine (compare figs. 40 and 44). NOx emissions were exceptionally low - Figs. 41 and 45; HC emissions were of the same general magnitude as those of the production gasoline engine (Figs. 42 and 46) but showed some increase at light load/low speed conditions.

In order to gain an approximate estimate of the likely fuel consumption and exhaust emissions of a vehicle powered by the methanol fuelled engine the steady state data derived from the mapping exercise was used in a Ricardo computer simulation program.

The results of the simulation exercise are recorded in Table 3. As anticipated, the fuel economy after making allowance for the low calorific value of the methanol fuel, was fairly high, NOx emissions were exceedingly low and HC emissions at 2.2 g/mile could probably have been reduced below the currently permitted level, .41 g/mile, by application of an exhaust oxidising catalyst. Although these results were interesting, since they clearly indicated the potential of a methanol burning HRCC engine to produce very low levels of NOx emissions and good fuel economy, it was recognised that with the very simple methanol carburettor fitted to the engine the control of fuelling so provided was insufficient to ensure acceptable vehicle driveability at the lean mixture strengths used in the engine mapping exercise. It was therefore decided to assess the fuel economy and exhaust emissions levels of the engine when operating with rather richer mixtures.

5.9 Performance Mapping at 0.8 Equivalence Ratio

Past experience with other gasoline fuelled HRCC engine had indicated that good vehicle driveability could be achieved with part load air/fuel ratios of about 18:1. It was therefore decided to aim for a similar mixture strength (approximately 0.8 equivalence ratio) over much of the part load range with the methanol fuelled engine.

In order to assess the likely fuel economy and exhaust emissions of the engine when operating at this equivalence ratio a further performance mapping exercise was conducted. The resulting maps are shown on Figs. 47-51 and the predicted 1975 FTP results using these data are given in Table 3.

With the richer mixture settings there was only a small decrease in engine and vehicle fuel economy - confirming the trends of the earlier mixture loops. However, significant changes occurred in NOx and HC emissions. NOx emissions were 6 to 10 times greater at low speed/load conditions, HC emissions were about 30% lower than those observed with the leaner mixture settings. Both of these results followed the general trends displayed by the mixture loops.

The predicted vehicle NOx emissions - 1.17 g/mile exceeded the original target value of 0.8 g/mile by a substantial amount. It was therefore apparent that in order to approach the target level while using a mixture strength of 0.8 equivalence ratio at most part load operating conditions, some additional means of NOx control was required.

The most conveniently available means of NOx control were use of retarded ignition timings or application of EGR. Experience had shown that, in the case of gasoline engines, attainment of worthwhile reductions in NOx emissions by means of retarded ignition timings involve a considerable trade-off in terms of increased fuel consumption. Use of moderate levels of EGR could produce useful reductions in NOx, an insignificant change in fuel consumption and a small increase in HC emissions. On balance it was considered that application of EGR would be the best means of controlling NOx emissions in the present exercise.

5.9 EGR System Development

To provide an initial assessment of the effects of EGR on the performance of the engine a simple supply circuit was installed. This circuit took exhaust gas from a point near the outlet of the exhaust manifold and passed it through a conventional vacuum operated control valve before adding it to the ingoing charge via a block sandwiched between the carburettor and the inlet manifold. The arrangement of this circuit is shown in Fig. 52. In order to determine the quantity of recirculated exhaust gas a sample pipe of 8 mm diameter was fitted into the inlet manifold directly below the carburettor. This permitted a sample of the ingoing mixture to be taken so that CO_2 level could be measured and EGR flow rate calculated.

For the first test the engine was operated at 40 rev/s, 2.5 bar with mixture strengths of 0.8 and 0.9 equivalence ratio. At each equivalence ratio the EGR flow rate was increased in stages from 0 to approximately 10% by progressively opening the control valve using a vacuum signal. The results of this test are shown on Fig. 53. It was apparent that EGR was very effective in reducing NOx emissions - a 50% reduction occurring with about 5% EGR. HC emissions increased by relatively little when using EGR and thermal efficiency was slightly improved. It was therefore concluded that use of EGR was an attractive means of controlling NOx emissions in this case.

In order to produce automatic control of EGR flow it was necessary to provide an appropriate vacuum signal to the EGR control valve. Measurements were made of required vacuum signal to provide suitable quantities of EGR at different engine operating conditions. Tests were then made to identify an appropriate tapping point in the carburettor body, slightly above the throttle butterfly, which would provide a vacuum signal approximating to that required. It was noted during this work that, especially at higher speed/load operating conditions, EGR flow rate was strongly influenced by exhaust back pressure. An arbitrary level of exhaust back pressure - 200 mm Hg at 90 rev/s - was therefore set by fitting a restrictor in the test bench exhaust system. This pressure was chosen as being representative of the level found in vehicle installations of gasoline engines where catalytic reactors were incorporated in the exhaust system.

With the EGR system functioning a mapping exercise was conducted over the engine's operating range in order to determine the variations in EGR flow rate. The results are shown on Fig. 54. It was considered that the EGR levels were broadly satisfactory with a maximum flow rate of atout 10% and very low levels at low speeds/loads, where significant quantities of EGR could adversely affect vehicle driveability, and at high loads which would be little used during 1975 FTP tests and were therefore relatively unimportant with regard to NOx level. Some further benefits in terms of lower FTP NOx emissions could probably have been obtained by moving the 'eye' of the map towards lower speeds, since during the FTP test with the vehicle configuration assumed for the computer simulation work, a considerable amount of the engine's operating time was spent in the speed range 30 to 50 rev/s.

5.10 Optimisation of Ignition Timing Settings

The high energy ignition system fitted to the engine incorporated a distributor having conventional automatic centrifugal and vacuum operated timing adjustment systems to provide spark advance with increasing engine speed and decreasing load respectively. A short series of tests were made to determine the 'as received' characteristics of these systems and also to identify the optimum, MBT, ignition timing requirements at full load and at part load when operating with a mixture strength of 0.8 equivalence ratio and with the EGR flow rate shown on Fig. 54. Modifications were then made to the distributor, including changes to the weights and springs controlling the centrifugal (speed) advance and to the vacuum capsule controlling the load advance, to obtain automatic timing characteristics which quite closely matched the optimum requirements - see Figs. 55 and 56.

It was noted during the testwork that the optimum timing during low speed/full load operation (approximately 10° BTDC at 20 rev/s WOT) was considerably less advanced than that required at idle (20-25° BTDC at 15 rev/s). This was due to the relatively rapid burn rate of the HRCC engine at full load when compared with conventional gasoline engines. In order to provide close to optimum timing at both conditions the vacuum signal to the distributor advance mechanism was taken directly from the inlet manifold rather than from a throttle edge tapping which is commonly used on conventional gasoline engines.

5.11 Mixture Strength Adjustments

A considerable amount of time was spent attempting to obtain the desired mixture strength conditions over the engine's operating range, i.e. approximately 0.8 equivalence ratio at light and medium loads with progressive enrichment to about 1.2 equivalence ratio at full load. As noted earlier the carburettor employed was a simple, single barrel, fixed choke device and had few means of mixture strength adjustment. After numerous tests during which the effects of changes to the various fuel and air metering jet sizes were comprehensively assessed it was concluded to be impossible to obtain either the desired equivalence ratio (0.8) over a significant portion of the part load operating range or the simultaneous achievement of a rich mixture (1.2 equivalence ratio) at full load and a lean mixture (circa 0.8) at part load conditions.

It appeared possible that fundamental modifications to the carburettor's fuel metering circuits could have, at least partly, overcome these difficulties. Only a single methanol proof carburettor was available and it was considered that major modifications to it, involving replacement of 'cast-in' metering jets and machining of new passages, incurred a substantial risk of irreparably damaging the unit. Such work would also result in removing the methanol proof phosphate coating from areas of the carburettor body, hence permitting chemical degradation of the material. It was therefore decided to retain the carburettor in its existing basic form with jet sizes selected to provide part load mixture strength as close as possible to that desired and to add a supplementary fuel circuit, controlled by throttle position, to enrichen the mixture at high load conditions.

This supplementary circuit comprised a small diameter tube taking fuel from the base of the carburettor float chamber and delivering it to the inlet tract below the throttle butterfly valve. A conventional jet was incorporated in the circuit to provide a means of modulating fuel flow rate and a methanol proof solenoid valve, activated by a micro switch on the throttle linkage, was used to provide on/off control at close to wide open throttle.

It was recognised that the mixture strength 'tune' resulting from this approach was far from ideal but it was considered to be the best which could be achieved with the available carburettor and in view of the cost and time constraints under which the project was conducted. On the test bed used for engine development it was not possible to fully assess the transient characteristics of the engine such as instability problems which might occur at the throttle position where the supplementary full circuit was activated. Far better control of mixture strength could be obtained by using a more sophisticated carburettor - such as a twin barrel device. No such carburettor, in methanol proof form, was available during the course of this project.

Using the carburettor in its modified form the mixture strength variations over the load and speed range shown in Fig. 57 were first obtained. Over much of the engine's operating range the resulting mixture strength was close to the desired level, at low speeds the carburettor produced rather lean mixture (0.75 equivalence ratio).

5.12 Fuel Economy and Emissions with Automatic Control of Operating Parameters

With the engine operating parameters - mixture strength, ignition timing and EGR rate - under automatic control a further performance mapping exercise was undertaken. The results are shown on Figs. 58-62 and the predicted 1975 FTP results using these data are given in Table 3.

Brake thermal efficiency was very similar overall to that exhibited during the previous mapping exercise. At low speeds the rather lean mixture strength produced by the carburettor was close to the optimum value for best economy while at higher speeds the adverse effect of the richer mixture was largely offset by the beneficial effect of EGR.

NOx emissions were relatively low, again due to the use of lean mixtures at low speeds and the presence of EGR at higher speeds. HC emissions were slightly increased relative to the previous mapping exercise (which used 0.8 equivalence ratio and no EGR) again due to mixture strength/ EGR effects.

These results were encouraging, ignition timing and EGR calibrations were considered to be close to optimum and, given the limitations of the carburettor, mixture strength control over much of the part load operating range appeared to be reasonable, with the exception of low speed conditions where lean mixtures were evident which could have incurred vehicle driveability problems.

5.13 Engine Starting Characteristics

It was anticipated that starting and driveability of the engine under cold operating conditions would be poor since there would be little heat available from the inlet manifold coolant jacket to vaporise the methanol fuel. As an attempt to overcome this problem it was decided to supplement coolant jacket heat with an electrical heater at these operating conditions.

Two types of heater were available, a 'hedgehog' type unit which could be fitted in the inlet manifold beneath the carburettor and a grid type device which could be installed in the inlet tract between the carburettor and the inlet manifold. Installation of a hedgehog unit in the engine's intake manifold would have been difficult and would have involved considerable modifications of the coolant jacket on the lower side of the manifold, which would have resulted in a reduction in mixture heating during normal 'hot' engine operation probably adversely affecting engine driveability. Installation of a grid type heater was much simpler and was considered to be much less likely to adversely affect general driveability although some small power loss was anticipated due to the restricting effect of the grid on inlet mixture flow. On balance it was decided that use of a grid type heater was the most convenient approach to this particular application.

The heating grid was fitted to the lower side of the block sandwiched, between the carburettor and inlet manifold, which was used to introduce EGR to the ingoing charge - see Fig. 63. The power supply to the heater was controlled by a thermostatic switch mounted in the engine coolant circuit so that it was energised when the coolant temperature was lower than about 35°C.

Other parameters likely to influence the engine operation under cold conditions included the inlet air temperature and the mixture strength. A production Volkswagen 'pancake' type, air cleaner suitable for direct mounting on the single choke carburettor was fitted to the engine. This air cleaner incorporated a thermostatically controlled flap valve so that hot air, drawn from around the exhaust manifold, could be induced in order to maintain a carburettor inlet temperature of about 35°C at low speed/ load operating conditions. The carburettor was fitted with a choke flap which was primarily manually controlled; manual selection of the fully closed choke position also partly opened the throttle butterfly to a 'fast idle' position. Two automatic override devices were incorporated in the choke control mechanism. One, vacuum operated, partly opened the choke flap in response to wide throttle openings. The other was a bi-metallic coil spring with an electrical heater element in close proximity to it. This heater was energised when the engine's ignition circuit was turned on, this produced expansion of the coil spring which progressively opened the choke. There was an inbuilt facility to permit the introduction of a time delay into the choke opening schedule produced by this coil spring/heater assembly and some adjustments were made to this.

Unfortunately it was not possible to test the starting ability of the engine under low temperature conditions. All development work was conducted in a normal engine test cell not provided with any climate control facilities. Some impressions of the engine's starting characteristics were obtained by monitoring its behaviour during the first start-ups made each day. Fig. 64 illustrates the changes in the main operating parameters duirng such a start-up. With the choke manually set to its fully closed position the throttle was slightly opened, to its fast idle position, by a cam on the choke lever. Before cranking the throttle was fully opened once - so activating the carburettor accelerator pump - and then allowed to return to its fast idle setting, operation of the starter motor would then produce regular firing in all cylinders within approximately 1 second where upon engine speed would rapidly rise to about 2200 rev/min when the engine was connected to the dynamometer - circa 3000 rev/min with the dynamometer disconnected. As indicated in Fig. 64 the closed choke position caused the mixture strength to be enriched to approximately 1.2 equivalence ratio (7% exhaust CO concentration). Automatic choke opening (by the coil spring/heater device) occurred after about 5 minutes in the example shown, earlier or later opening could be produced by adjustment of the choke mechanism.

Observations of starting behaviour were made both with and without the heater in the inlet tract energised. This made no apparent difference to engine starting ability at the prevailing temperatures (12-15°C) at which these tests were made.

It was, in the absence of specific tests, impossible to predict the minimum temperature at which reliable engine starting could be achieved when using pure methanol fuel. The general impression gained from extensive operation of the engine during the development programme was that unaided starting should be possible at quite low ambient temperatures - probably below 5°C; with the inlet heater operational starting might be possible at considerably lower temperatures.

The minimum starting temperatures when using methanol fuel in the HRCC engine are likely to be rather lower than those found to be possible with conventional combustion chambers. The reason for this is that the high compression ratio of the HRCC unit ensures relatively high compression temperatures and hence a greater likelihood of vaporising the fuel in the cylinders and producing an ignitible mixture in the vicinity of the spark plugs.

5.14 Idle Operation

With the engine in its final build form, i.e. with air cleaner and inlet heater grid fitted, tests were made to assess its performance at idle. Two standard tests were carried out with the speed held constant at 15 rev/s - the normal setting for production VW engines of this type. First ignition timing was held constant at 19° BTDC and mixture strength was varied in stages by adjustment of the carburettor idle screws, this permitted identification of the mixture strength for minimum fuel consumption. In the second test the mixture strength was held constant at the previously identified optimum value while ignition timing was varied.

The results of this work (shown on Figs. 65-70) indicated that with optimum mixture strength and ignition timing settings minimum idle fuel consumption was 960 g/h - equivalent to 435 g/h of gasoline - while HC emissions were approximately 15 g/h. Previous tests with the gasoline fuelled Ricardo research HRCC engine had produced best results of 530 g/h gasoline consumption with 21 g/h HC emissions at the same operating conditions, while a production 1.6 l Volkswagen gasoline engine exhibited corresponding figures of 800 g/h gasoline consumption and 23 g/h HC emissions. The results of these tests are illustrated on Fig. 71.

5.15 Engine Performance in Final Build

The final build of the HRCC engine, in which it would be fitted to a vehicle, included automatic control of all operating parameters, fuelling, ignition timing and EGR rate, and the presence of the air cleaner and inlet heater grid. In order to enrichen the mixture strength at low speeds/loads, to ensure good vehicle driveability, some changes were made to carburettor jets; the carburettor specification finally derived was:-

venturi diameter	22 mm
main fuel jet	190
air corrector/emulsion tube	100 Z
pilot fuel jet	55
pilot air corrector/emulsion tube	72.5
supplementary enrichment fuel jet	110

This produced variations in equivalence ratio as shown on Fig. 72. Although still far from the desired condition of 0.8 equivalence ratio over much of the low and mid load operating range it was concluded that the carburettor used offered little scope for further improvement in mixture strength control. The supplementary enrichment system produced compromise equivalence ratios fairly close to optimum throughout the speed range at full load.

In order to determine the maximum performance of the engine in its final form and to assess the losses incurred by the presence of the air cleaner and inlet heater grid, measurements were made of full load performance in two builds. Both builds included the air cleaner, automatic ignition timing and mixture strength control (with the supplementary mixture enrichment circuit operational) and a restrictor in the exhaust system in order to produce levels of exhaust back pressure similar to those likely to be encountered in a vehicle installation. The inlet heater grid was omitted in the first build but fitted for the second.

Comparison of the results of the first build with those obtained during earlier tests - section 5.3 - permitted an assessment of the effects of the air cleaner and a vehicle exhaust system on engine performance to be made. The second build was effectively the final build of the engine and so permitted the likely performance when installed in a vehicle to be assessed.

In addition the effects of the inlet heater grid on engine performance could be determined by comparing the results achieved with the first and second builds.

The results achieved with both builds are shown on Figs. 73-75. As was anticipated, the presence of the air cleaner and significant exhaust back pressure reduced the volumetric efficiency of the engine, somewhat surprisingly the greatest reduction occurred at low speeds, perhaps due to the occurrence of adverse pressure pulsation effects within the intake system. The addition of the heater brought about a further significant efficiency at mid-high speeds.

The relatively crude supplementary enrichment system provided a mixture strength at low speed which was richer than that found to be optimum during the earlier full load tests. Conversely, over most of the speed range the mixture strength was considerably leaner than that used previously. Despite this, no combustion irregularities such as knock or pre-ignition were evident and the brake thermal efficiency was considerably higher than that observed previously.

The good performance of the engine with mixture strengths significantly leaner than those previously found to be optimum was at first attributed to improvements in cylinder to cylinder mixture distribution and mixture preparation brought about by the changes made to the intake system i.e. introduction of a sandwich block (for addition of EGR) between the carburettor and the inlet manifold and fitting of the air cleaner. However, investigations showed that another feature - a gas sample probe fitted to the inlet manifold - played a significant part in the achievement of good mixture distribution. This sample probe, the location of which is shown on Fig. 76, has been fitted to permit measurement of EGR rate. In order to maintain the beneficial effects of this probe, while assuring good durability, a solid steel bar having the same external dimensions was fitted in its place.

The effects of the air cleaner, exhaust back pressure and the inlet heater grid on BMEP and power output can be appreciated from comparisons of Figs. 20 and 73. Without the heater grid maximum BMEP and power output decreased by only a small amount. With the heater unit fitted a more significant performance loss was evident (due to the reduction in volumetric efficiency), but nevertheless the general level of performance compared quite favourably with that produced by gasoline engines of similar displacement fitted with single barrel carburettors.

In order to assess the part load performance of the engine in its final build a further mapping exercise was conducted. The results are shown on Figs. 77-81. Variations of BSFC and thermal efficiency over the engine's operating range were very similar to those observed during previous mapping exercises. NOx emissions, Fig. 79, were significantly increased compared with the results obtained with leaner mixture strength settings - Fig. 60. HC emissions, Fig. 80, were slightly reduced, again due to the employment of a rather richer mixture strength.

Computer predictions of vehicle fuel economy and exhaust emissions, Table 3, suggested that with the final engine specification and despite the short-comings attributable to the carburettor fuel economy would be little changed from the previously predicted values. NOx emissions were likely to be increased to approximately 1 g/mile while engine-out HC emissions would probably be slightly reduced, to about 1.4 g/mile.

5.16 Aldehyde Emissions

Aldehyde emissions from methanol fuelled engines are generally reported as being considerably higher than those produced by gasoline fuelled units.

During the present project aldehyde emissions produced by the engine when methanol fuelled were measured on two occasions - firstly during the course of a mixture loop at 40 rev/s, 2.5 bar and secondly during the final part load mapping exercise. The results obtained during the mixture loop are plotted on Fig. 29, the results of the mapping exercise are noted on Fig. 82.

The aldehyde emissions broadly exhibited the anticipated variation with mixture strength, i.e. a low level with stoichiometric fuelling, and a higher level of leaner mixtures. Few reports of similar tests could be found in the literature but those which were located (18) generally indicated continually increasing aldehyde emissions with leaner mixture strengths.

The results shown on Fig. 26 could therefore be considered rather surprising in that aldehydes were slightly lower in the range 0.6-0.7 equivalence ratio than at 0.8-0.9. The sampling technique and analysis method used in the present exercise had been used by Ricardo in numerous other investigations and appeared to produce repeatable, accurate results. It was therefore concluded that the observed relationship between aldehyde emissions and mixture strength was due to the combustion characteristics of HRCC engines.

As indicated on Fig. 82, the general level of aldehyde emissions over the part load operating range was of the order of 0.5 g/kWh. Comparison with limited available data relating to similar methanol fuelled, spark ignited, engines suggest that this level was quite low. It is difficult to draw meaningful conclusions regarding the variation of aldehyde emissions over the engine's operating range since two parameters - mixture strength and EGR rate - were varying simultaneously with engine speed and load.

5.17 General Engine Condition

During the development testwork the engine was run for a total of about 300 hours, for approximately 80 of which it was gasoline fuelled, with methanol operation accounting for the remainder.

The cylinder head was removed twice during the project - after about

120 and 200 hours respectively - in order to check the condition of the cylinders, pistons, valves etc. On both occasions no major components showed any signs of distress and apart from light lapping of the valves no remedial work was required. Combustion chamber deposits - both on the cylinder head surfaces and the piston crown - were quite light and gave no cause for concern.

Some white/grey powdery deposits occurred in the inlet ports, manifold and the lower part of the carburettor. These deposits formed only a thin film on the various surfaces and apart from the need to occasionally remove them from the idle air passage of the carburettor (where their presence caused slight idle instability) they caused no problems. Discussions with Volkswagen revealed that such deposits had also been observed during their work with methanol fuel. They were attributed to chemical reactions between the methanol and the small quantities of engine lubricating oil which passed down the inlet valve stems.

The lubricating oil used in the engine was a conventional commerical product (Castrol GTX 15W-50) rated SF/CC. Oil changes were made after 80 hours (when changing from gasoline to methanol fuel) and after 50 and 150 hours of engine operation on methanol. During these two latter changes samples of used oil were analysed for fuel dilution, TBN and viscosity; the results were:-

	Test Method	Fresh Oil	50 hour sample	150 hour sample
Fuel Dilution % Vol	IP23	No Dilution		<.05
TBN mgKOH/g	IP276	9.20	6.34	4.67
Viscosity @ 40°C mm^2/s	IP71	123.10	96.75	102.4

The results were not significantly different to those which might be anticipated following similar periods of engine operation with gasoline fuel. Engine oil consumption was low at approximately 1 pint/150 hours of operation.

Spark plugs (Champion BN60Y) were routinely changed at frequent intervals during the project. No signs of plug degradation were observed except during pre-ignition tests with a rather less cold plug grade (BN6Y) when damage to the insulator around the central electrode, and in one case to the ground electrode, was observed. With the BN60Y plugs, despite this being a very cold grade, no problems such as plug wetting during engine start up were observed.

No signs of chemical attack by methanol of any of the engine's fuel system components were noted.

6. SUMMARY OF THE DEVELOPMENT WORK

The baseline tests on the EPA HRCC engine using gasoline fuel indicated that its performance was broadly similar to that of a nominally identical, Ricardo research, HRCC engine tested previously. Full load performance was, in fact, slightly better and at part load conditions the observed small variations in thermal efficiency and exhaust emissions could be accounted for by the inevitable small differences occurring between two engines, e.g. in inlet tract and combustion system dimensions, in engine friction levels and test installations. Using 98 RON gasoline the full load performance was knock limited over much of the speed range; the octane requirement of the engine was found to be about 101 RON - typical of HRCC engines having a 13:1 compression ratio and significantly lower than that generally observed with other combustion chamber forms at the same compression ratios.

After fitting the appropriate inlet manifold and carburettor the full load performance when using methanol fuel was slightly inferior to that achieved during the earlier gasoline tests. This degradation could be largely attributed to the adverse effect of the single barrel methanol carburettor on volumetric efficiency. The cylinder to cylinder mixture distribution was also poor, necessitating the employment of fairly rich mixture strengths and penalising thermal efficiency. Optimum (MBT) ignition timings could be used at full load at all speeds reflecting the high octane quality of methanol and the modest octane requirement of the HRCC combustion system, even at 13:1 compression ratio.

Pre-ignition was found to be avoided by a wide margin when using an appropriate, cold, grade of spark plugs. These plugs, Champion BN60Y, appeared to produce good engine operation at all conditions and were apparently not prone to problems of fouling during engine starts.

At part load conditions, mixture loops indicated that methanol operation produced higher thermal efficiency than was achieved with gasoline fuelling due to lower combustion temperatures, which reduced heat losses, and the larger quantity of combustion products formed when burning methanol. The mixture strength for best economy was generally found to be at an equivalence ratio of about 0.7, this was rather leaner than in the case of gasoline fuelling and might be attributable to the faster flame speeds associated with methanol combustion. NOx emissions were much lower than during gasoline operation, this resulted from the lower combustion temperatures which were in turn primarily caused by the high latent heat of vaporisation of methanol. HC emissions were significantly lower during methanol operation, partly due to the relative insensitivity of the FID analyser to the unburnt fuel emissions.

A part load performance mapping exercise suggested that operation at the best economy mixture strength, circa 0.7 equivalence ratio, would produce good vehicle fuel economy (at least on an energy basis) and very low NOx emissions. However, it was felt that the limitations in mixture strength control*, an inherent feature of the relatively unsophisticated carburettor which was employed, would heavily penalise driveability when using such lean mixtures. Therefore it was considered necessary to operate rather richer than this. Accordingly the mapping exercise was repeated using a part load mixture strength of 0.8 equivalence ratio; this produced only a small fuel economy penalty but a large increase in NOx emissions.

In order to reduce NOx emissions a simple EGR system was developed and fitted to the engine. Tests showed that EGR was a very effective means of NOx control - 5% EGR produced a reduction on NOx emissions of approximately 50%, a small gain in thermal efficiency and a relatively small increase (15-20%) in HC emissions.

Modifications to the distributor provided automatic ignition timing variations over the speed/load operating range of the engine which were very close to optimum. Tuning of the carburettor to provide automatic control of mixture strength at the equivalence ratios desired - 0.8 over most of the part load operating range and 1.1-1.2 at full load - proved to be impossible. A supplementary full load enrichment circuit, controlled by throttle position, was added to the carburettor. With this, mixture strength at full load was close to ideal but at part loads the desired equivalence ratio - 0.8 - could only be attained over a small part of the engine's operating range.

In order to improve the cold starting performance of the engine a grid type of electrical heater was incorporated in the inlet tract between the carburettor and inlet manifold. Tests indicated that the presence of this heater had a small adverse effect on volumetric efficiency and hence on full load BMEP and power output. It was not possible to investigate the effects of the device on the engine's cold starting ability. During general development work immediate, unaided, starting was consistently achieved at ambient temperatures of around 12°C.

The full load performance of the engine in its final 'vehicle' build exhibited maximum BMEP of 9.6 bar and a maximum power output of 53 kW. These were considered to be acceptable figures which compared favourably with results achieved by gasoline engines of similar displacement fitted with single barrel carburettors.

The part load performance mapping exercise conducted with the engine in its final build form indicated that despite the far from ideal mixture strength control provided by the carburettor thermal efficiency was very similar to that observed during earlier mapping exercises. NOx emissions were higher, primarily due to the rather richer mixture strength supplied over much of the operating range. HC emissions were slightly lower, again due to the use of generally richer mixture strengths. FTP cycle simulation results suggested that vehicle fuel economy would be similar to earlier predictions but NOx emissions would be increased to about 1 g/mile; 'engine-out' HC emissions predicted to be 1.4 g/mile, could most probably be reduced to less than the target value of 0.2 g/mile by application of an exhaust oxidation catalyst.

The aldehyde emissions produced by the engine were measured at numerous part load operating conditions. The general levels compared quite favourably with limited published data relating to other methanol fuelled engines.

The condition of the engine both during and at the end of the test programme was generally unaffected by the use of methanol. Light deposits were observed in the inlet system, these were attributed to a chemical reaction between the fuel and the small quantities of lubricating oil passing down the valve guides. Combustion chamber deposits were very light and gave no cause for concern. The Champion BN60Y spark plugs appeared to offer good service characteristics, no plug fouling was observed. A commercial lubricating oil was used and exhibited no signs of abnormal degradation which could be attributed to the use of methanol fuel.

7. CONCLUSIONS

A prototype optimum engine for methanol utilisation incorporating a Ricardo HRCC combustion system was successfully developed during this project.

The performance of the engine on gasoline fuel was typical of HRCC units, indicating a 10% fuel economy advantage over conventional, low compression ratio, combustion systems. The engine's octane requirement - approximately 101 RON - was typical of HRCC units and considerably lower than that of a conventional combustion system at the same, 13:1, compression ratio.

In its final methanol build form with automatic control of fuelling, ignition timing and EGR the engine was entirely free of detonation and preignition and appeared likely to provide good vehicle driveability, moderately low exhaust emissions and reasonable fuel economy. Maximum power output was 53 kW, and was limited primarily by the use of a single barrel carburettor. Using a computer simulation program 'engine-out' emission levels and fuel consumption over the 1975 FTP test cycle of a 2375 lb car powered by the engine were predicted to be:

HC - 1.35 g/mile
NOx - 0.98 "
CO - 1.75 "
Fuel Consumption - 14.7 miles/US gallon (methanol)
30.3 miles/US gallon (gasoline equivalent)

When methanol fuelled the maximum thermal efficiency of the engine at part load was higher than when using gasoline and occurred at a leaner mixture strength. At such mixture strengths CO and NOx emissions were very low; HC emissions were moderately low and could be considerably reduced by application of an exhaust oxidation catalyst. The simple methanol proof carburettor fitted to the engine could not provide sufficient control of fuelling to ensure good vehicle driveability with the optimum, lean, mixture strengths. A richer mixture calibration was therefore employed for the final engine build.

Unaided starting was easily achieved at ambient temperatures of 10-15°C. An inlet charge heater was fitted to the engine to assist starting at lower temperatures.

The fuel consumption (on an energy basis) at idle was significantly lower than that of conventional and HRCC gasoline engines.

Aldehyde emissions were moderately high but application of an exhaust oxidation catalyst should effectively overcome this problem.

Following 220 hours of methanol operation the general engine condition was highly satisfactory. No problems which could be attributed to methanol utilisation were observed. Engine operation at low temperatures was not investigated.

8. RECOMMENDATIONS FOR FURTHER WORK

1. The performance of the engine when fitted in a vehicle equipped with an exhaust oxidation catalyst and a suitable secondary air supply system should be assessed.

2. Mixture strength control over the engine's operating range should be improved by installing a more sophisticated (twin barrel) carburettor. Following this the improvements in all aspects of engine performance - power output, torque, fuel economy, exhaust emissions and vehicle driveability - should be investigated.

3. The cold starting ability of the engine should be determined. Changes to the inlet charge heater - its design and installed position may be advantageous.

4. The possibility of increasing the engine's compression ratio with a view to obtaining better fuel economy will still retaining full load operation free of knock and pre-ignition should be assessed.

5. Engine packaging could be improved by changing to an ignition distributor of smaller dimensions.

6. Engine durability should be investigated.

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TABLE 1

FUEL SPECIFICATION

4-STAR PETROL (BS 4040:1971)

TEST	METHOD	RESULT
Appearance	Visual	Clear and bright No visible impurities
Colour	Visual	Yellow
Relative Density @ 60/60°F	IP160	0.7466
Reid Vapour Pressure lbf/in^2	IP69	12.1
Distillation	IP123	
IBP°C		30.0
10% recovered @ °C		47.0
50%		100.5
90%		165.0
FBP°		203.0
Recovery % vol		98.0
Residue % vol		1.0
Existent Gum mg/100 ml	IP131	1
Sulphur Content	IP107	0.04
Copper Corrosion @ 50°C	IP154	1
Lead Content g/US gal	A.A.	1.36
Phosphorus Content g/US gal	UOP 353 (mod)	0.27
Oxidation Stability mms	IP40	>1000
Octane Number:		
Research Method	IP237	97.9
Motor Method	IP236	88.9
Hydrocarbon Types:	IP156	
Aromatic Content % vol		35.4
Unsaturates % vol		9.3
Saturates Content % vol		55.3
Carbon Content	Elemental	86.58
Hydrogen Content		13.37
Stoichiometric Air/Fuel Ratio		14.6
Calorific Value kJ/kg		43960
Latent Heat of Vaporisation kJ/kg		400

TABLE 2

FUEL SPECIFICATION

METHANOL (BS 506:1966)

Appearance	Clear, colourless, free from suspended matter and sediment
Relative Density @ 15.5/15.5°C	0.798-0.795
IBP°C	>64.5
95% @ °C	<65.25
FBP°C	<65.5
Water Content	<0.5% by weight (measured - 571 ppm)
Aldehydes and Ketones	<.015% by weight, as acetone
Alkalinity	<.0005% by weight, as ammonia
Acidity	<.003% by weight, as formic acid
Sulphur and Sulphur Compounds	<.0001% by weight, as sulphur
Composition % by weight	
Carbon	37.5
Hydrogen	12.5
Oxygen	50.0
Octane Quality (from literature)	
RON	104-114
MON	87-97
Stoichiometric Air/Fuel Ratio	6.46
Measured Calorific Value kJ/kg	19940
Latent Heat of Vaporisation kJ/kg (from literature)	1100

TABLE 3

PREDICTED FTP RESULTS USING RICARDO COMPUTER SIMULATED PROGRAM

		HC	CO	NOx	Miles/gal	
		(gram/mile)			(methanol)	(gasoline equivalent)
1.	Best Economy Mixture Strength No EGR (Figures 39 to 43)	2.17	2.78	0.30	14.73	30.43
2.	0.8 Equivalence Ratio No EGR (Figures 47 to 51)	1.61	2.07	1.17	13.95	28.82
3.	Initial Auto Mixture (Lean) with EGR (Figures 58 to 61)	1.87	2.22	0.62	14.73	30.44
4.	Final Auto Mixture with EGR (Figures 77 to 81)	1.35	1.75	0.98	14.67	30.31

APPENDIX

TABULATED TEST RESULTS

```
EPA 1.5L HRCC ENGINE                                                      REFER TO FIGS. 4 - 6

           13:1CR

                              FULL LOAD POWER CURVE

BORE       STROKE      NUMBER OF      CYCLE       BRAKE      AIR METER      FUEL      H/CARBON     CALORIFIC     TURBOCHARGED
                       CYLINDERS      TYPE       CONSTANT    CONSTANT       S.G.       RATIO         VALUE         OPTION
79.50       73.00        4             4.         9.0640      .000000       .7380       1.80       43960.00          0

 DAY        MONTH        YEAR        TEST       BAROMETER    WET BULB     DRY BULB     POWER        FRICTION        OUTPUT
                                     NUMBER                 TEMPERATURE  TEMPERATURE  CORRECTION     OPTION         OPTION
  6           7           82          2.00       766.50       18.00        22.50        1             1.              4


  1 ENGINE SPEED (REV/S)               20.00  30.00  40.00  50.00  60.00  70.00  80.00  90.00
  2 BRAKE LOAD                          5.50   6.10   6.40   6.40   6.58   6.65   6.44   6.10
  3 FUEL MASS ( GRAMS )               100.00 100.00 150.00 150.00 200.00 200.00 250.00 250.00
  5 FUEL TIME ( SEC )                  91.70  49.70  68.50  51.90  56.20  48.55  54.60  51.60
  6 FUEL TEMPERATURE ( C )             30.00  31.00  31.00  30.00  27.00  27.00  28.00  28.00
  8 AIR METER TEMPERATURE ( C )        28.00  33.00  37.00  37.00  33.00  36.00  38.00  38.00
 12 HYDROCARBONS ( PPMC )             3300.0 4200.0 2550.0 2850.0 2700.0 2550.0 2400.0 2400.0
 13 CARBON MONOXIDE ( % )              4.100  9.600  2.600  4.500  3.800  3.700  3.500  3.200
 14 OXIDES OF NITROGEN ( PPM )         860.0  160.0 1890.0 1750.0 1900.0 2200.0 2000.0 2050.0
 15 CARBON DIOXIDE ( % )              12.500  9.400 13.400 12.400 12.500 12.800 13.000 13.300
 16 OXYGEN ( % )                        .500   .300   .650   .350   .500   .350   .350   .250
 28 IGNITION TIMING                      .00   8.00   4.00  11.00  12.00  14.00  14.00  11.00
 26 EXHAUST TEMPERATURE                521.0  546.0  669.0  706.0  703.0  746.0  772.0  797.0
 11 INTAKE MANIFOLD PRESS.(mm.Hg)        .00    .00    .00    .00    .00    .00    .00    .00
```

```
            EPA 1.5L HRCC ENGINE                                          REFER TO FIGS. 4 - 6

                          13:1CR

   DATE  6/ 7/82     TEST NO.  2.0    BAROMETER 766.50 MM.HG      WET BULB TEMP(C) 18.0
                                                                  DRY BULB TEMP(C) 22.5
   RELATIVE HUMIDITY              = 64.49
   HUMIDITY CORRECTION FACTOR    =  1.00
   GRAINS OF WATER/LB DRY AIR    = 76.10

                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

   POWERS CORRECTED TO DIN.70020
   ------------------------------

 SPEED   POWER     BMEP    TORQUE    FUEL    VOLUMETRIC        AIR FUEL      B.T.E.    H C      NOX       C O      CO2     HC + NOX
 REV/S    KW       BAR      N.M    G/KW.HR EFFICIENCY(%)        RATIO          %    G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR

 20.0    12.20     8.41    97.06    323.5    82.1(     .0)    12.9(     .0)    25.32     6.31     5.49   158.73   760.36    11.80
 30.0    20.46     9.41   108.53    358.8    86.4(     .0)    10.9(     .0)    22.83     7.76      .99   359.34   552.84     8.75
 40.0    28.80     9.94   114.61    279.1    89.6(     .0)    13.6(     .0)    29.34     4.38    10.84    90.46   732.50    15.22
 50.0    36.01     9.94   114.61    294.7    88.4(     .0)    12.7(     .0)    27.79     4.89    10.03   156.36   676.98    14.92
 60.0    44.13    10.15   117.07    294.1    91.8(     .0)    13.1(     .0)    27.84     4.79    11.27   136.67   706.37    16.06
 70.0    52.29    10.31   118.90    288.8    91.8(     .0)    13.0(     .0)    28.36     4.39    12.67   129.20   702.29    17.06
 80.0    58.06    10.01   115.52    290.0    90.5(     .0)    13.1(     .0)    28.24     4.16    11.58   122.85   716.95    15.73
 90.0    61.87     9.48   109.42    288.0    85.5(     .0)    13.2(     .0)    28.44     4.13    11.78   111.53   728.35    15.91
```

```
RICARDO 1.5L HRCC ENGINE                                                   REFER TO FIGS. 4 - 6

        FULL LOAD PERFORMANCE

                    (79.5*73.4)(1457.4c.c) 13:1CR 240 CAMSHA

BORE     STROKE    NUMBER OF     CYCLE      BRAKE      AIR METER     FUEL      H/CARBON   CALORIFIC   TURBOCHARGER
                   CYLINDERS     TYPE       CONSTANT   CONSTANT      S.G.      RATIO      VALUE       OPTION
79.50     73.40       4           4.        33.4717    .000000       .7500      1.80      44000.00       0

DAY      MONTH      YEAR      TEST       BAROMETER   WET BULB      DRY BULB      POWER        FRICTION      OUTPUT
                              NUMBER                 TEMPERATURE   TEMPERATURE   CORRECTION   OPTION        OPTION
19         9         81       77.00       755.15      16.40         23.30         1            1.            4

 1 ENGINE SPEED (REV/S)              20.00   30.00   40.00   50.00   60.00   70.00   80.00   90.00  100.00
 2 BRAKE LOAD                        19.40   21.20   23.30   22.90   23.20   23.70   22.80   21.10   19.50
 3 FUEL MASS ( GRAMS )              100.00  100.00  150.00  200.00  200.00  200.00  200.00  200.00  300.00
 5 FUEL TIME ( SEC )                 97.65   64.50   66.11   74.62   52.65   46.21   38.80   39.20   53.77
 6 FUEL TEMPERATURE ( C )            22.00   23.00   23.00   23.00   24.00   25.00   25.00   25.00   27.00
 8 AIR METER TEMPERATURE ( C )       30.00   38.00   24.00   35.00   36.00   38.00   36.00   38.00   40.00
12 HYDROCARBONS ( PPMC )            3240.0  2820.0  2820.0  2700.0  3000.0  2820.0  2850.0  2580.0  2460.0
13 CARBON MONOXIDE ( % )             6.300   5.100   5.500   5.600   7.600   6.500   7.200   6.000   6.200
14 OXIDES OF NITROGEN ( PPM )        700.0   900.0   950.0  1700.0  1200.0  1800.0  1500.0  1800.0  1800.0
15 CARBON DIOXIDE ( % )             11.100  11.800  11.600  11.700  10.500  11.000  10.700  11.400  11.100
16 OXYGEN ( % )                       .200    .300    .300    .350    .300    .400    .300    .300    .400
28 IGNITION TIMING                    1.00   10.00   13.00   15.00   17.00   16.00   18.00   18.00   18.00
26 EXHAUST TEMPERATURE               424.0   511.0   567.0   597.0   607.0   656.0   657.0   687.0   699.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)     -6.75   -6.00   -8.25  -12.00  -18.00  -25.50  -30.00  -36.00  -39.00
```

```
              RICARDO 1.5L HRCC ENGINE                                              REFER TO FIGS. 4 - 6

                           FULL LOAD PERFORMANCE

   DATE 19/ 9/81      TEST NO. 77.0    BAROMETER 755.15 MM.HG      WET BULB TEMP(C) 16.4
                                                                   DRY BULB TEMP(C) 23.3
   RELATIVE HUMIDITY              = 49.02
   HUMIDITY CORRECTION FACTOR     =   .95
   GRAINS OF WATER/LB DRY AIR     = 61.43

                  ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                  : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                  ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

   POWERS CORRECTED TO DIN.70020
   -----------------------------

 SPEED   POWER    BMEP    TORQUE   FUEL    VOLUMETRIC        AIR FUEL        B.T.E.    H C      NOX      C O      CO2     HC + NOX
 REV/S    KW      BAR      N.M   G/KW.HR  EFFICIENCY(%)       RATIO            %     G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR

  20.0   11.86    8.14    94.41   318.0    72.5(    .0)    11.9(    .0)    25.73    5.81     3.96   229.05   634.08     9.77
  30.0   19.70    9.01   104.52   293.7    78.3(    .0)    12.5(    .0)    27.85    4.82     4.85   176.66   642.21     9.67
  40.0   28.21    9.68   112.26   293.4    81.1(    .0)    12.3(    .0)    27.89    4.76     5.05   188.07   623.23     9.81
  50.0   35.30    9.69   112.36   282.1    79.7(    .0)    12.3(    .0)    29.01    4.33     8.60   182.15   597.95    12.94
  60.0   42.98    9.83   114.02   328.8    88.7(    .0)    11.6(    .0)    24.88    5.36     6.76   275.19   597.38    12.12
  70.0   51.39   10.07   116.85   314.4    90.4(    .0)    12.0(    .0)    26.03    4.99    10.03   232.82   619.08    15.02
  80.0   56.32    9.66   112.05   340.5    91.4(    .0)    11.7(    .0)    24.03    5.34     8.85   273.17   637.87    14.19
  90.0   58.83    8.97   104.03   323.7    83.9(    .0)    12.2(    .0)    25.27    4.73    10.40   222.88   665.38    15.13
 100.0   60.60    8.31    96.45   344.8    82.9(    .0)    12.1(    .0)    23.73    4.83    11.15   246.83   694.35    15.98
```

OCTANE REQUIREMENT TESTS - REFER TO FIG. 7

AUTO CARBURATION

SPEED (rev/s)	98 RON GASOLINE BMEP (bar)	CO (%)	MBT/KL (°BTDC)	105 RON GASOLINE BMEP (bar)	CO (%)	MBT/KL (°BTDC)
30	9.3	9.6	-/8	9.3	9.0	15/35
40	9.7	2.6	-/6	10.0	2.5	18/32
50	9.7	5.0	-/11	9.9	6.2	21/36

REFER TO FIGS. 8-10 & 26-28

```
            EPA 1.5L HRCC ENGINE

                   13:1CR

   DATE 19/ 7/82     TEST NO. 10.0    BAROMETER 772.00 MM.HG     WET BULB TEMP(C) 17.2
                                                                 DRY BULB TEMP(C) 25.0
   RELATIVE HUMIDITY             = 45.06
   HUMIDITY CORRECTION FACTOR =    .95
   GRAINS OF WATER/LB DRY AIR  = 61.16

                  ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                  : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                  ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                     RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER    BMEP    TORQUE    FUEL    VOLUMETRIC          AIR FUEL        B.T.E.     H C      NOX      C O      CO2     HC + NOX
REV/S    KW      BAR      N.M    G/KW.HR  EFFICIENCY(%)         RATIO            %     G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR

20.0    2.16     1.49    17.21    551.3    26.4(     .0)     13.7(     .0)    14.86    19.43    11.27   138.15  1476.02    30.70
20.0    2.16     1.49    17.21    501.5    26.9(     .0)     15.2(     .0)    16.33    17.69    18.89    10.54  1523.50    36.58
20.0    2.16     1.49    17.21    497.0    28.3(     .0)     16.1(     .0)    16.48    17.53    17.25     9.62  1511.16    34.77
20.0    2.16     1.49    17.21    485.4    31.0(     .0)     18.0(     .0)    16.87    18.01    18.27    10.54  1471.29    36.27
20.0    2.16     1.49    17.21    549.4    37.4(     .0)     19.3(     .0)    14.90    28.57    18.64    12.51  1638.55    47.20
```

```
RICARDO 1.5L HRCC ENGINE

        MIXTURE LOOP @ 20REV/S 1.5BAR                                    REFER TO FIGS. 8-10

                          (79.5,73.4,1457.4cc)13:1CR 240CAMSHAFT

BORE      STROKE    NUMBER OF     CYCLE     BRAKE     AIR METER    FUEL     H/CARBON   CALORIFIC   TURBOCHARGER
                    CYLINDERS     TYPE     CONSTANT    CONSTANT    S.G.      RATIO       VALUE       OPTION
79.50     73.40         4          4.      33.4717     .000000     .7500      1.80     44000.00        0

DAY       MONTH       YEAR       TEST     BAROMETER   WET BULB     DRY BULB     POWER      FRICTION      OUTPUT
                                NUMBER               TEMPERATURE  TEMPERATURE CORRECTION    OPTION       OPTION
21          9          81       79.00      757.30      18.90        25.60         0           1.            4

 1 ENGINE SPEED (REV/S)             20.00  20.00  20.00  20.00  20.00
 2 BRAKE LOAD                        3.66   3.66   3.66   3.66   3.66
 3 FUEL MASS ( GRAMS )              20.00  20.00  20.00  20.00  20.00
 5 FUEL TIME ( SEC )                66.87  69.01  72.34  71.34  70.26
 6 FUEL TEMPERATURE ( C )           23.00  23.00  23.00  25.00  25.00
 8 AIR METER TEMPERATURE ( C )      28.00  28.00  28.00  29.00  29.00
12 HYDROCARBONS ( PPMC )           4320.0 3780.0 3300.0 3180.0 3420.0
13 CARBON MONOXIDE ( % )            2.300   .500   .100   .100   .100
14 OXIDES OF NITROGEN ( PPM )       600.0  800.0 1000.0  600.0  200.0
15 CARBON DIOXIDE ( % )            13.600 14.500 14.000 13.100 11.400
16 OXYGEN ( % )                      .450   .900  2.200  3.000  5.100
28 IGNITION TIMING                  13.00  13.00  15.00  16.00  17.00
26 EXHAUST TEMPERATURE              258.0  263.0  267.0  267.0  278.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-468.00-466.50-466.50-453.75-420.75
```

REFER TO FIGS. 8-10

```
              RICARDO 1.5L HRCC ENGINE

                          MIXTURE LOOP @ 20REV/S 1.5BAR

    DATE 21/ 9/81     TEST NO. 79.0    BAROMETER 757.30 MM.HG     WET BULB TEMP(C) 18.9
                                                                  DRY BULB TEMP(C) 25.6
    RELATIVE HUMIDITY            = 52.79
    HUMIDITY CORRECTION FACTOR  =  1.00
    GRAINS OF WATER/LB DRY AIR  = 75.94

                  :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                  : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                  :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER     BMEP    TORQUE   FUEL    VOLUMETRIC         AIR FUEL        B.T.E.    H C       NOX       C O       CO2      HC + NOX
REV/S   KW        BAR     N.M     G/KW.HR  EFFICIENCY(%)       RATIO           %       G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

20.0     2.19     1.50    17.40    492.3    23.7(    .0)      13.5(    .0)    16.62     13.02      6.04    140.48   1305.19     19.06
20.0     2.19     1.50    17.40    477.1    24.7(    .0)      14.5(    .0)    17.15     11.73      8.29     31.43   1432.06     20.01
20.0     2.19     1.50    17.40    455.1    25.4(    .0)      15.6(    .0)    17.98     10.41     10.53      6.39   1405.68     20.94
20.0     2.19     1.50    17.40    461.5    26.9(    .0)      16.3(    .0)    17.73     10.86      6.84      6.92   1423.74     17.70
20.0     2.19     1.50    17.40    468.6    30.7(    .0)      18.3(    .0)    17.46     13.53      2.64      8.02   1436.07     16.18
```

```
               RICARDO 1.5L HRCC ENGINE
                                                                      REFER TO FIGS. 8-10
                             MIXTURE LOOP @ 20REV/S 1.5BAR

      DATE 21/ 9/81       TEST NO. 79.0     BAROMETER 757.30 MM.HG      WET BULB TEMP(C) 18.9
      RELATIVE HUMIDITY                 = 52.79                          DRY BULB TEMP(C) 25.6
      HUMIDITY CORRECTION FACTOR  =  1.00
      GRAINS OF WATER/LB DRY AIR   = 75.94

                         :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                         : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                         :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                           RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA
SPEED   POWER    BMEP   TORQUE   FUEL     VOLUMETRIC        AIR FUEL        B.T.E.   H C      NOX      C O      CO2      HC + NOX
REV/S   KW       BAR    N.M      G/KW.HR  EFFICIENCY(%)     RATIO           %        G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR

20.0    2.19     1.50   17.40    492.3    23.7(   .0)       13.5(   .0)     16.62    13.02     6.04    140.48   1305.19   19.06
20.0    2.19     1.50   17.40    477.1    24.7(   .0)       14.5(   .0)     17.15    11.73     8.29     31.43   1432.06   20.01
20.0    2.19     1.50   17.40    455.1    25.4(   .0)       15.6(   .0)     17.98    10.41    10.53      6.39   1405.68   20.94
20.0    2.19     1.50   17.40    461.5    26.9(   .0)       16.3(   .0)     17.73    10.86     6.84      6.92   1423.74   17.70
20.0    2.19     1.50   17.40    468.6    30.7(   .0)       18.3(   .0)     17.46    13.53     2.64      8.02   1436.07   16.18
```

```
EPA 1.5L HRCC ENGINE

         13:1CR                                                                  REFER TO FIGS. 11-13 & 29-31

                                   MIXTURE LOOP AT 40REV/S 2.5BMEP BAR

BORE       STROKE      NUMBER OF       CYCLE       BRAKE      AIR METER      FUEL      H/CARBON    CALORIFIC    TURBOCHARGED
                       CYLINDERS       TYPE       CONSTANT    CONSTANT       S.G.       RATIO       VALUE         OPTION
79.50       73.00          4            4.          9.0640     .000000       .7380       1.80      43960.00         0

 DAY       MONTH         YEAR         TEST       BAROMETER    WET BULB     DRY BULB     POWER       FRICTION        OUTPUT
                                     NUMBER                  TEMPERATURE  TEMPERATURE  CORRECTION    OPTION         OPTION
 16          7            82          7.00         765.50      17.50        24.00         1           1.              4


 1 ENGINE SPEED (REV/S)             40.00  40.00  40.00  40.00  40.00  40.00
 2 BRAKE LOAD                        1.64   1.64   1.64   1.64   1.64   1.64
 3 FUEL MASS ( GRAMS )              50.00  50.00  50.00  50.00  50.00  50.00
 5 FUEL TIME ( SEC )                62.10  65.50  67.30  69.00  68.90  58.00
 6 FUEL TEMPERATURE ( C )           26.00  26.00  27.00  27.00  27.00  28.00
 8 AIR METER TEMPERATURE ( C )      30.00  31.00  31.00  31.00  32.00  32.00
12 HYDROCARBONS ( PPMC )           3480.0 3540.0 3150.0 3150.0 3300.0 7500.0
13 CARBON MONOXIDE ( % )            1.800   .200   .100   .100   .090   .140
14 OXIDES OF NITROGEN ( PPM )      1700.0 3080.0 3020.0 1500.0  325.0   60.0
15 CARBON DIOXIDE ( % )            13.700 14.400 13.300 11.700 10.200  8.000
16 OXYGEN ( % )                      .700  1.550  3.100  5.150  7.000 10.000
28 IGNITION TIMING                  19.00  22.00  24.00  27.00  31.00  39.00
26 EXHAUST TEMPERATURE              515.0  519.0  504.0  484.0  471.0  455.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-435.00-427.50-412.50-390.00-352.50-262.50
```

```
                    EPA 1.5L HRCC ENGINE                         REFER TO FIGS. 11-13 & 29-31

                              13:1CR

     DATE 16/ 7/82      TEST NO.  7.0     BAROMETER 765.50 MM.HG      WET BULB TEMP(C) 17.5
                                                                      DRY BULB TEMP(C) 24.0
     RELATIVE HUMIDITY              = 52.21
     HUMIDITY CORRECTION FACTOR  =    .97
     GRAINS OF WATER/LB DRY AIR  = 67.41

                        ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                        : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                        ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                           RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

     POWERS CORRECTED TO DIN.70020
     -----------------------------

   SPEED   POWER    BMEP    TORQUE    FUEL    VOLUMETRIC        AIR FUEL       B.T.E.     H C       NOX      C O       CO2     HC + NOX
   REV/S    KW      BAR      N.M    G/KW.HR  EFFICIENCY(%)        RATIO           %     G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR

   40.0    7.31    2.52    29.07    400.5    32.8(    .0)     13.9(    .0)    20.45     8.79     13.89     92.16  1102.17    22.68
   40.0    7.32    2.52    29.12    379.7    34.0(    .0)     15.1(    .0)    21.57     8.99     25.28     10.29  1164.01    34.27
   40.0    7.32    2.52    29.12    369.6    35.8(    .0)     16.4(    .0)    22.16     8.49     26.30      5.46  1140.86    34.79
   40.0    7.32    2.52    29.12    360.4    39.1(    .0)     18.3(    .0)    22.72     9.37     14.43      6.03  1108.17    23.80
   40.0    7.33    2.53    29.17    361.0    44.1(    .0)     20.6(    .0)    22.69    11.22      3.57      6.20  1103.70    14.79
   40.0    7.33    2.53    29.17    428.8    62.2(    .0)     24.4(    .0)    19.10    36.18       .94     13.68  1228.44    37.11
```

```
RICARDO 1.5L HRCC ENGINE                                              REFER TO FIGS. 11-13

         MIXTURE LOOP @ 40REV/S 2.5BAR

                           (79.5,73.4,1457.4cc)13:1CR 240CAMSHAFT

BORE       STROKE     NUMBER OF     CYCLE       BRAKE      AIR METER      FUEL      H/CARBON    CALORIFIC   TURBOCHARGED
                      CYLINDERS     TYPE      CONSTANT    CONSTANT       S.G.       RATIO        VALUE        OPTION
79.50       73.40        4           4.       33.4717     .000000       .7500       1.80       44000.00         0

DAY        MONTH        YEAR        TEST     BAROMETER    WET BULB     DRY BULB     POWER       FRICTION        OUTPUT
                                   NUMBER               TEMPERATURE  TEMPERATURE  CORRECTION    OPTION         OPTION
21           9           81        78.00     755.15       16.40        23.30         0           1.              2


 1 ENGINE SPEED (REV/S)            40.00  40.00  40.00  40.00  40.00  40.00
 2 BRAKE LOAD                       6.10   6.10   6.10   6.10   6.10   6.10
 3 FUEL MASS ( GRAMS )             50.00  50.00  50.00  50.00  50.00  50.00
 5 FUEL TIME ( SEC )               55.40  63.82  65.67  66.56  66.08  65.53
 6 FUEL TEMPERATURE ( C )          25.00  24.00  24.00  24.00  24.00  24.00
 8 AIR METER TEMPERATURE ( C )     31.00  34.00  33.00  34.00  33.00  33.00
12 HYDROCARBONS ( PPMC )          3480.0 2670.0 2280.0 2160.0 2100.0 2400.0
13 CARBON MONOXIDE ( % )           4.700   .800   .110   .100   .100   .100
14 OXIDES OF NITROGEN ( PPM )      700.0 1700.0 1900.0 2000.0 1550.0  900.0
15 CARBON DIOXIDE ( % )           12.100 14.600 14.400 13.500 12.600 11.900
16 OXYGEN ( % )                     .300   .600  1.500  2.350  3.400  4.600
28 IGNITION TIMING                 11.00  15.00  15.00  17.00  19.00  21.00
26 EXHAUST TEMPERATURE             412.0  444.0  449.0  445.0  439.0  435.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-429.00-434.25-419.25-418.50-402.00-375.00
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                RICARDO 1.5L HRCC ENGINE                                   REFER TO FIGS. 11-13

                           MIXTURE LOOP @ 40REV/S 2.5BAR

      DATE 21/ 9/81     TEST NO. 78.0     BAROMETER 755.15 MM.HG      WET BULB TEMP(C) 16.4
                                                                      DRY BULB TEMP(C) 23.3
      RELATIVE HUMIDITY               = 49.02
      HUMIDITY CORRECTION FACTOR      =   .95
      GRAINS OF WATER/LB DRY AIR      = 61.43

                :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                  RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED    POWER     BMEP     TORQUE    FUEL    VOLUMETRIC        AIR FUEL         B.T.E.     H C       NOX       C O       CO2     HC + NOX
REV/S     KW       BAR       N.M    G/KW.HR  EFFICIENCY(%)       RATIO             %     G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

40.0      7.29     2.50     29.01    445.7    33.7(     .0)    12.6(     .0)    18.36      9.05      5.74    247.52   1001.22     14.78
40.0      7.29     2.50     29.01    386.9    33.6(     .0)    14.3(     .0)    21.15      6.59     13.23     40.03   1147.82     19.83
40.0      7.29     2.50     29.01    376.0    34.7(     .0)    15.2(     .0)    21.76      5.82     15.28      5.69   1169.56     21.10
40.0      7.29     2.50     29.01    371.0    35.9(     .0)    15.9(     .0)    22.05      5.80     16.93      5.44   1153.99     22.73
40.0      7.29     2.50     29.01    373.7    38.1(     .0)    16.8(     .0)    21.90      6.08     14.14      5.86   1161.02     20.22
40.0      7.29     2.50     29.01    376.8    40.9(     .0)    17.9(     .0)    21.71      7.39      8.73      6.24   1166.25     16.12
```

```
EPA 1.5L HRCC ENGINE                                                         REFER TO FIGS. 14-16 & 32-34

         13:1CR

                                   MIXTURE LOOP AT 40REV/S 5.5BMEP BAR

BORE       STROKE      NUMBER OF      CYCLE      BRAKE       AIR METER      FUEL       H/CARBON    CALORIFIC    TURBOCHARGED
                       CYLINDERS      TYPE      CONSTANT     CONSTANT       S.G.        RATIO        VALUE         OPTION
79.50       73.00        4             4.         9.0640      .000000       .7380        1.80       43960.00        0

 DAY        MONTH        YEAR        TEST      BAROMETER     WET BULB     DRY BULB      POWER        FRICTION          OUTPUT
                                    NUMBER                  TEMPERATURE  TEMPERATURE  CORRECTION      OPTION           OPTION
 20           7           82        11.00       770.00        17.20        25.00          0            1.                4


 1 ENGINE SPEED (REV/S)           40.00  40.00  40.00  40.00  40.00  40.00
 2 BRAKE LOAD                      3.60   3.60   3.60   3.60   3.60   3.60
 3 FUEL MASS ( GRAMS )           100.00 100.00 100.00 100.00 100.00 100.00
 5 FUEL TIME ( SEC )              74.70  79.60  80.70  82.20  83.60  82.40
 6 FUEL TEMPERATURE ( C )         27.00  28.00  28.00  29.00  30.00  29.00
 8 AIR METER TEMPERATURE ( C )    32.00  33.00  32.00  33.00  33.00  34.00
12 HYDROCARBONS ( PPMC )         3480.0 3240.0 2850.0 2850.0 3090.0 3360.0
13 CARBON MONOXIDE ( % )          1.300   .120   .095   .095   .100   .100
14 OXIDES OF NITROGEN ( PPM )    2580.0 4000.0 4000.0 3600.0 1400.0 1000.0
15 CARBON DIOXIDE ( % )          14.100 14.000 13.500 12.200 10.300  9.700
16 OXYGEN ( % )                    .750  2.050  3.150  5.100  7.000  7.800
28 IGNITION TIMING                16.00  20.00  23.00  26.00  33.00  37.00
26 EXHAUST TEMPERATURE            595.0  587.0  568.0  544.0  524.0  516.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-256.50-247.50-225.00-191.25-138.75-112.50
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                    EPA 1.5L HRCC ENGINE
                                                      REFER TO FIGS. 14-16 & 32-34
                             13:1CR

     DATE 20/ 7/82     TEST NO. 11.0    BAROMETER 770.00 MM.HG     WET BULB TEMP(C) 17.2
                                                                   DRY BULB TEMP(C) 25.0
     RELATIVE HUMIDITY               = 45.11
     HUMIDITY CORRECTION FACTOR  =    .95
     GRAINS OF WATER/LB DRY AIR   = 61.38

                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER     BMEP    TORQUE   FUEL     VOLUMETRIC        AIR FUEL      B.T.E.    H C       NOX       C O       CO2       HC + NOX
REV/S   KW        BAR     N.M      G/KW.HR  EFFICIENCY(%)      RATIO          %      G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

40.0    15.89     5.48    63.21    303.3     55.6(    .0)     14.1(    .0)   27.00     6.70     15.66     50.74     864.64     22.37
40.0    15.89     5.48    63.21    284.7     57.5(    .0)     15.5(    .0)   28.77     6.39     24.85      4.79     878.40     31.23
40.0    15.89     5.48    63.21    280.8     59.8(    .0)     16.4(    .0)   29.16     5.77     25.50      3.89     869.43     31.27
40.0    15.89     5.48    63.21    275.7     65.2(    .0)     18.2(    .0)   29.71     6.25     24.86      4.22     851.08     31.11
40.0    15.89     5.48    63.21    271.1     72.5(    .0)     20.5(    .0)   30.21     7.82     11.17      5.13     829.94     18.99
40.0    15.89     5.48    63.21    275.0     77.7(    .0)     21.6(    .0)   29.78     9.12      8.55      5.50     837.80     17.67
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REFER TO FIGS. 14-16

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RICARDO 1.5L HRCC ENGINE

        MIXTURE LOOP @ 40REV/S 5.5BAR

                      (79.5,73.4,1457.4cc)13:1CR 240CAMSHAFT

BORE      STROKE     NUMBER OF      CYCLE      BRAKE     AIR METER      FUEL      H/CARBON   CALORIFIC  TURBOCHARGED
                     CYLINDERS      TYPE     CONSTANT    CONSTANT       S.G.       RATIO      VALUE       OPTION
79.50      73.40        4            4.       33.4717     .000000       .7500       1.80     44000.00       0

DAY       MONTH        YEAR        TEST     BAROMETER    WET BULB     DRY BULB     POWER      FRICTION      OUTPUT
                                  NUMBER               TEMPERATURE  TEMPERATURE  CORRECTION   OPTION        OPTION
23         9            81        78.00      759.80       17.00        24.70         0          1.             4


 1 ENGINE SPEED (REV/S)           40.00  40.00  40.00  40.00  40.00  40.00  40.00  40.00
 2 BRAKE LOAD                     13.41  13.41  13.41  13.41  13.41  13.14  13.14  13.14
 3 FUEL MASS ( GRAMS )           100.00 100.00 100.00 100.00 100.00 100.00 100.00 100.00
 5 FUEL TIME ( SEC )              64.30  69.38  75.65  79.66  83.30  83.86  84.07  82.08
 6 FUEL TEMPERATURE ( C )         22.00  23.00  23.00  24.00  24.00  25.00  24.00  25.00
 8 AIR METER TEMPERATURE ( C )    31.00  33.00  32.00  34.00  33.00  34.00  33.00  33.00
12 HYDROCARBONS ( PPMC )         3020.0 3090.0 2640.0 2220.0 2040.0 1920.0 1920.0 2010.0
13 CARSON MONOXIDE ( % )          6.600  4.600  2.400   .900   .200   .100   .100   .100
14 OXIDES OF NITROGEN ( PPM )    1000.0 1450.0 2500.0 3500.0 3600.0 3400.0 3100.0 2200.0
15 CARBON DIOXIDE ( % )          10.900 12.200 13.400 14.000 13.450 12.800 12.100 11.400
16 OXYGEN ( % )                    .200   .300   .600  1.400  2.600  3.400  4.250  5.250
28 IGNITION TIMING                11.00  13.00  15.00  17.50  19.00  20.00  21.00  21.00
26 EXHAUST TEMPERATURE            492.0  503.0  512.0  517.0  516.0  513.0  506.0  503.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-236.25-241.50-241.50-229.50-212.25-201.75-180.75-157.50
```

REFER TO FIGS. 14-16

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                RICARDO 1.5L HRCC ENGINE

                        MIXTURE LOOP @ 40REV/S 5.5BAR

     DATE 23/ 9/81     TEST NO. 78.0    BAROMETER 759.80 MM.HG     WET BULB TEMP(C) 17.0
                                                                   DRY BULB TEMP(C) 24.7
     RELATIVE HUMIDITY             = 45.57
     HUMIDITY CORRECTION FACTOR    =   .95
     GRAINS OF WATER/LB DRY AIR    = 61.73

                    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER   BMEP   TORQUE   FUEL      VOLUMETRIC        AIR FUEL      B.T.E.    H C       NOX       C O       CO2       HC + NOX
REV/S   KW      BAR    N.M      G/KW.HR   EFFICIENCY(%)     RATIO         %         G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

40.0    16.03   5.50   63.77    349.4     54.4(     .0)     11.8(   .0)   23.42     5.93       6.19     262.44    680.99    12.12
40.0    16.03   5.50   63.77    323.8     54.1(     .0)     12.6(   .0)   25.27     5.85       8.66     176.38    735.02    14.51
40.0    16.03   5.50   63.77    296.9     53.5(     .0)     13.7(   .0)   27.55     4.88      14.59      89.89    788.57    19.47
40.0    16.03   5.50   63.77    282.0     55.5(     .0)     14.8(   .0)   29.01     4.14      20.60      34.01    831.14    24.74
40.0    16.03   5.50   63.77    269.7     57.3(     .0)     16.1(   .0)   30.34     3.97      22.12       7.89    833.49    26.09
40.0    15.70   5.39   62.48    273.4     59.8(     .0)     16.8(   .0)   29.93     4.01      22.41       4.23    850.90    26.42
40.0    15.70   5.39   62.48    272.7     62.4(     .0)     17.6(   .0)   30.00     4.23      21.53       4.46    847.68    25.76
40.0    15.70   5.39   62.48    279.3     67.6(     .0)     18.7(   .0)   29.29     4.80      16.58       4.84    866.31    21.37
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EPA 1.5L HRCC ENGINE

          13:1CR                                                                  REFER TO FIGS. 17-19 & 35-37

                                     MIXTURE LOOP AT 60REV/S 4.0BMEP BAR

BORE        STROKE      NUMBER OF      CYCLE       BRAKE      AIR METER      FUEL      H/CARBON    CALORIFIC   TURBOCHARGED
                        CYLINDERS      TYPE       CONSTANT    CONSTANT       S.G.       RATIO       VALUE        OPTION
79.50         73.00        4            4.          9.0640     .000000       .7380       1.80      43960.00        0

 DAY        MONTH         YEAR        TEST      BAROMETER     WET BULB     DRY BULB     POWER      FRICTION        OUTPUT
                                     NUMBER                  TEMPERATURE  TEMPERATURE  CORRECTION   OPTION         OPTION
 16           7            82         8.00       766.30        17.50        25.00         0          1.              4


 1 ENGINE SPEED (REV/S)             60.00  60.00  60.00  60.00  60.00  60.00
 2 BRAKE LOAD                        2.63   2.63   2.63   2.63   2.63   2.63
 3 FUEL MASS ( GRAMS )             100.00 100.00 100.00 100.00 100.00 100.00
 5 FUEL TIME ( SEC )                59.50  63.70  64.70  65.80  66.00  61.00
 6 FUEL TEMPERATURE ( C )           28.00  30.00  32.00  31.00  32.00  31.00
 8 AIR METER TEMPERATURE ( C )      34.00  36.00  36.00  36.00  36.00  36.00
12 HYDROCARBONS ( PPMC )           3000.0 2850.0 3300.0 2850.0 3300.0 6000.0
13 CARBON MONOXIDE ( % )            1.700   .150   .100   .100   .100   .150
14 OXIDES OF NITROGEN ( PPM )      2500.0 4000.0 4000.0 2600.0  850.0  125.0
15 CARBON DIOXIDE ( % )            13.800 13.800 13.000 11.700 10.200  8.000
16 OXYGEN ( % )                      .400  2.300  3.400  5.150  7.100  9.800
28 IGNITION TIMING                  21.00  22.00  29.00  31.00  35.00  48.00
26 EXHAUST TEMPERATURE              650.0  648.0  626.0  600.0  575.0  528.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-337.50-322.50-300.00-270.00-225.00-127.50
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                    EPA 1.5L HRCC ENGINE

                              13:1CR                          REFER TO FIGS. 17-19 & 35-37

     DATE 16/ 7/82      TEST NO.  8.0    BAROMETER 766.30 MM.HG     WET BULB TEMP(C) 17.5
                                                                    DRY BULB TEMP(C) 25.0
     RELATIVE HUMIDITY             = 47.02
     HUMIDITY CORRECTION FACTOR    =   .96
     GRAINS OF WATER/LB DRY AIR    = 64.33

                    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER    BMEP    TORQUE    FUEL     VOLUMETRIC        AIR FUEL      B.T.E.    H C       NOX       C O       CO2       HC + NOX
REV/S    KW      BAR      N.M    G/KW.HR  EFFICIENCY(%)        RATIO         %     G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR    G/KW.HR

60.0    17.41    4.00    46.18    347.5    45.9(    .0)     13.8(    .0)   23.56     6.60     17.55     75.76     966.33     24.15
60.0    17.41    4.00    46.18    324.6    49.3(    .0)     15.7(    .0)   25.23     6.50     29.11      6.93    1001.85     35.61
60.0    17.41    4.00    46.18    319.6    51.2(    .0)     16.6(    .0)   25.62     7.85     30.38      4.82     984.88     38.24
60.0    17.41    4.00    46.18    314.3    55.7(    .0)     18.3(    .0)   26.06     7.41     21.58      5.27     968.58     28.99
60.0    17.41    4.00    46.18    313.3    62.4(    .0)     20.6(    .0)   26.14     9.73      8.00      5.97     957.07     17.72
60.0    17.41    4.00    46.18    339.0    80.4(    .0)     24.6(    .0)   24.16    23.24      1.55     11.77     986.67     24.79
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RICARDO 1.5L HRCC ENGINE

         MIXTURE LOOP @ 60REV/S 4.0BAR                                                  REFER TO FIGS. 17-19

                           (79.5,73.4,1457.4cc)13:1CR 240CAMSHAFT

BORE       STROKE      NUMBER OF       CYCLE        BRAKE       AIR METER       FUEL       H/CARBON    CALORIFIC    TURBOCHARGED
                       CYLINDERS       TYPE        CONSTANT      CONSTANT       S.G.        RATIO        VALUE        OPTION
79.50       73.40         4             4.          33.4717       .000000       .7500        1.80       44000.00         0

DAY        MONTH          YEAR         TEST       BAROMETER    WET BULB      DRY BULB      POWER        FRICTION        OUTPUT
                                      NUMBER                  TEMPERATURE   TEMPERATURE  CORRECTION      OPTION         OPTION
23           9             81          81.00       765.40        15.20         21.70         0             1.             4


 1 ENGINE SPEED (REV/S)            60.00   60.00   60.00   60.00   60.00   60.00   60.00
 2 BRAKE LOAD                       9.76    9.76    9.76    9.76    9.76    9.76    9.76
 3 FUEL MASS ( GRAMS )            150.00  150.00  150.00  150.00  150.00  150.00  150.00
 5 FUEL TIME ( SEC )               86.44   95.54   98.00  100.72  101.60  102.84  102.40
 6 FUEL TEMPERATURE ( C )          23.00   25.00   25.00   25.00   25.00   25.00   25.00
 8 AIR METER TEMPERATURE ( C )     33.00   35.00   35.00   35.00   35.00   35.00   35.00
12 HYDROCARBONS ( PPMC )          3540.0  2400.0  2100.0  2220.0  2040.0  2040.0  2190.0
13 CARBON MONOXIDE ( % )           3.950    .400    .200    .150    .100    .100    .100
14 OXIDES OF NITROGEN ( PPM )     1650.0  3100.0  3200.0  2800.0  2200.0  1600.0  1000.0
15 CARBON DIOXIDE ( % )           12.550  14.500  14.000  13.200  12.400  11.400  10.600
16 OXYGEN ( % )                     .300   1.000   2.000   2.950   4.100   5.100   6.100
28 IGNITION TIMING                 16.00   18.00   19.00   20.00   20.00   23.00   24.00
26 EXHAUST TEMPERATURE             557.0   584.0   582.0   573.0   569.0   557.0   553.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-348.00-336.00-322.50-313.50-288.75-275.25-250.50
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                RICARDO 1.5L HRCC ENGINE                                    REFER TO FIGS. 17-19

                           MIXTURE LOOP @ 60REV/S 4.0BAR

      DATE 23/ 9/81     TEST NO. 81.0    BAROMETER 765.40 MM.HG     WET BULB TEMP(C) 15.2
      RELATIVE HUMIDITY                 = 49.52                     DRY BULB TEMP(C) 21.7
      HUMIDITY CORRECTION FACTOR        =   .92
      GRAINS OF WATER/LB DRY AIR        = 55.48

                ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                  RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA
SPEED   POWER     BMEP    TORQUE   FUEL     VOLUMETRIC         AIR FUEL       B.T.E.    H C      NOX       C O       CO2      HC + NOX
REV/S    KW       BAR      N.M   G/KW.HR  EFFICIENCY(%)         RATIO           %     G/KW.HR  G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR
 60.0   17.50     4.00    46.41    357.1    43.8(    .0)     12.8(    .0)    22.91     7.50    10.73    169.56    846.45     18.23
 60.0   17.50     4.00    46.41    323.1    45.9(    .0)     14.7(    .0)    25.33     5.12    20.30     17.29    984.99     25.42
 60.0   17.50     4.00    46.41    315.0    47.2(    .0)     15.6(    .0)    25.98     4.59    21.46      8.86    974.12     26.05
 60.0   17.50     4.00    46.41    306.4    48.2(    .0)     16.3(    .0)    26.70     5.01    19.40      6.86    948.83     24.41
 60.0   17.50     4.00    46.41    303.8    51.0(    .0)     17.4(    .0)    26.93     4.88    16.14      4.85    943.98     21.02
 60.0   17.50     4.00    46.41    300.1    53.5(    .0)     18.5(    .0)    27.26     5.23    12.59      5.20    930.64     17.82
 60.0   17.50     4.00    46.41    301.4    57.2(    .0)     19.7(    .0)    27.14     6.05     8.47      5.59    931.53     14.52
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EPA 1.5L HRCC VW ENGINE
                                                                                    REFER TO FIGS. 20-22
           13:1 CR

                                        FULL LOAD POWER CURVE

BORE       STROKE     NUMBER OF      CYCLE      BRAKE     AIR METER      FUEL      H/CARBON    CALORIFIC   TURBOCHARGED
                      CYLINDERS      TYPE      CONSTANT   CONSTANT       S.G.       RATIO       VALUE        OPTION
79.50       73.00        4            4.        9.0640     .000000      .8180        4.00      19940.00         0

 DAY        MONTH        YEAR        TEST      BAROMETER   WET BULB     DRY BULB     POWER       FRICTION        OUTPUT
                                    NUMBER               TEMPERATURE  TEMPERATURE  CORRECTION     OPTION          OPTION
 16           8           82        94.00       762.10      17.00        23.00         1            1.              4


 1 ENGINE SPEED (REV/S)              20.00  30.00  40.00  50.00  60.00  70.00  80.00  90.00
 2 BRAKE LOAD                         5.25   6.10   6.56   6.65   6.50   6.42   6.15   5.55
 3 FUEL MASS ( GRAMS )              150.00 200.00 250.00 250.00 250.00 250.00 250.00 250.00
 5 FUEL TIME ( SEC )                 65.00  54.70  52.96  38.20  32.60  28.00  25.40  23.20
 6 FUEL TEMPERATURE ( C )            22.00  22.00  22.00  23.00  25.00  23.00  23.00  25.00
 8 AIR METER TEMPERATURE ( C )       26.00  26.00  26.00  25.00  30.00  31.00  34.00  35.00
12 HYDROCARBONS ( PPMC )          -1710.0-2280.0-1680.0-1485.0-1410.0-4950.0-1890.0-1980.0
13 CARBON MONOXIDE ( % )             5.000  4.400  3.700  5.600  5.640  5.700  5.400  5.500
14 OXIDES OF NITROGEN ( PPM )     -1820.0-1890.0-1430.0 -840.0 -780.0 -930.0-1000.0-1000.0
15 CARBON DIOXIDE ( % )             11.400 12.100 12.600 12.300 11.200 11.300 11.500 11.500
16 OXYGEN ( % )                       .900   .700   .600   .500   .450   .450   .500   .500
28 IGNITION TIMING                    9.00  12.00  15.00  18.00  20.00  23.00  24.00  25.00
26 EXHAUST TEMPERATURE               397.0  477.0  547.0  564.0  591.0  620.0  639.0  650.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)       .00    .00    .00    .00    .00    .00    .00    .00
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                    EPA 1.5L HRCC VW ENGINE
                                                         REFER TO FIGS. 20-22
                             13:1 CR

   DATE 16/ 8/82     TEST NO. 94.0    BAROMETER 762.10 MM.HG     WET BULB TEMP(C) 17.0
                                                                 DRY BULB TEMP(C) 23.0
   RELATIVE HUMIDITY             = 54.51
   HUMIDITY CORRECTION FACTOR    =  1.26
   GRAINS OF WATER/LB DRY AIR    = 66.55

                    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

   POWERS CORRECTED TO DIN.70020
   -----------------------------

 SPEED   POWER     BMEP     TORQUE    FUEL     VOLUMETRIC          AIR FUEL          B.T.E.    H C      NOX      C O       CO2      HC + NOX
 REV/S    KW       BAR       N.M     G/KW.HR  EFFICIENCY(%)         RATIO              %     G/KW.HR  G/KW.HR  G/KW.HR   G/KW.HR   G/KW.HR

 20.0    11.67     8.05     92.87    717.2     74.0(    .0)       5.5(    .0)       25.17     4.78    13.73    188.67    675.88     18.51
 30.0    20.34     9.35    107.91    651.9     79.4(    .0)       5.6(    .0)       27.69     5.77    12.91    149.36    645.35     18.68
 40.0    29.16    10.06    116.04    587.0     79.0(    .0)       5.7(    .0)       30.76     3.90     8.97    114.99    615.26     12.86
 50.0    36.89    10.18    117.44    642.3     81.5(    .0)       5.4(    .0)       28.11     3.48     5.16    173.82    599.86      8.64
 60.0    43.63    10.03    115.75    641.6     79.4(    .0)       5.3(    .0)       28.14     3.45     5.80    185.91    580.08      9.25
 70.0    50.36     9.93    114.51    648.3     77.9(    .0)       5.2(    .0)       27.85    11.84     7.00    183.17    570.55     18.84
 80.0    55.41     9.56    110.24    652.8     78.4(    .0)       5.3(    .0)       27.66     4.69     8.62    179.80    601.62     13.30
 90.0    56.34     8.64     99.64    703.9     76.3(    .0)       5.3(    .0)       25.65     5.26     9.60    196.20    644.58     14.87
 20REV/S 1.5BAR

          MIXTURE LOOP
                                                                     REFER TO FIGS. 26-28
                          BN60Y

BORE      STROKE    NUMBER OF    CYCLE     BRAKE     AIR METER    FUEL     H/CARBON  CALORIFIC  TURBOCHARGED
                    CYLINDERS     TYPE    CONSTANT    CONSTANT    S.G.      RATIO      VALUE       OPTION
79.50      73.00       4           4.       9.0640     .000281    .8180     4.00     19940.00        0

 DAY      MONTH       YEAR       TEST    BAROMETER   WET BULB    DRY BULB    POWER      FRICTION      OUTPUT
                                NUMBER              TEMPERATURE TEMPERATURE CORRECTION   OPTION       OPTION
 14         9          82       43.00     768.50      18.00       22.50        0           1.            4


 1 ENGINE SPEED (REV/S)            20.00  20.00  20.00  20.00  20.00
 2 BRAKE LOAD                        .98    .98    .98    .98    .98
 3 FUEL MASS ( GRAMS )             50.00  50.00  50.00  50.00  50.00
 5 FUEL TIME ( SEC )               70.80  76.60  77.40  81.00  79.30
 6 FUEL TEMPERATURE ( C )          26.00  26.00  26.00  26.00  27.00
 7 AIR METER READING               12.50  13.70  14.10  16.20  17.50
 9 AIR METER DEPRESSION (mm.Hg)      .44    .49    .51    .57    .61
 8 AIR METER TEMPERATURE ( C )     25.00  25.00  25.00  25.00  25.00
12 HYDROCARBONS ( PPMC )         -1710.0-1620.0-1650.0-2100.0-2550.0
13 CARBON MONOXIDE ( % )           1.650   .170   .160   .140   .150
14 OXIDES OF NITROGEN ( PPM )     -145.0 -300.0 -300.0  -95.0  -40.0
15 CARBON DIOXIDE ( % )           13.600 13.300 12.800 10.500  9.600
16 OXYGEN ( % )                     .400  2.500  3.100  6.300  7.700
28 IGNITION TIMING                 12.00  15.00  20.00  25.00  28.00
26 EXHAUST TEMPERATURE             265.0  262.0  258.0  254.0  259.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-480.00-465.00-453.75-427.50-412.50
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                20REV/S 1.5BAR

                            MIXTURE LOOP                                    REFER TO FIGS. 26-28

      DATE 14/ 9/82     TEST NO. 43.0    BAROMETER 768.50 MM.HG     WET BULB TEMP(C) 18.0
                                                                     DRY BULB TEMP(C) 22.5
      RELATIVE HUMIDITY               = 64.46
      HUMIDITY CORRECTION FACTOR      =   .94
      GRAINS OF WATER/LB DRY AIR      = 75.86

                      ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                      ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                         RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA
SPEED   POWER    BMEP    TORQUE   FUEL     VOLUMETRIC      AIR FUEL     B.T.E.   H C      NOX      C O      CO2      HC + NOX
REV/S   KW       BAR     N.M      G/KW.HR  EFFICIENCY(%)   RATIO        %        G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR

20.0     2.16    1.49    17.21    1175.7   25.0( 23.9)     6.1(  5.9)   15.36     8.44    1.83     109.65   1420.10   10.27
20.0     2.16    1.49    17.21    1086.7   26.9( 26.2)     7.2(  7.0)   16.61     8.19    3.98      11.81   1452.19   12.17
20.0     2.16    1.49    17.21    1075.5   27.4( 27.0)     7.4(  7.2)   16.79     8.51    4.07      11.43   1436.49   12.58
20.0     2.16    1.49    17.21    1027.7   31.3( 31.0)     8.8(  8.7)   17.57    12.05    1.47      11.55   1360.92   13.51
20.0     2.16    1.49    17.21    1049.7   34.8( 33.5)     9.6(  9.2)   17.20    15.95     .68      13.69   1377.11   16.63
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40REV/S 2.5BAR

         MIXTURE LOOP

                         BN60Y                                                           REFER TO FIGS. 29-31

BORE       STROKE     NUMBER OF     CYCLE      BRAKE      AIR METER     FUEL      H/CARBON   CALORIFIC   TURBOCHARGED
                      CYLINDERS      TYPE     CONSTANT    CONSTANT      S.G.       RATIO       VALUE        OPTION
79.50       73.00         4           4.       9.0640      .000281      .8180       4.00      19940.00         0

 DAY        MONTH       YEAR        TEST     BAROMETER    WET BULB    DRY BULB     POWER      FRICTION       OUTPUT
                                   NUMBER               TEMPERATURE TEMPERATURE CORRECTION     OPTION        OPTION
  8           9          82        38.00      767.80      17.50       21.20         0            1.             4


 1 ENGINE SPEED (REV/S)               40.00  40.00  40.00  40.00  40.00  40.00
 2 BRAKE LOAD                          1.64   1.64   1.64   1.64   1.64   1.64
 3 FUEL MASS ( GRAMS )               100.00 100.00 100.00 100.00 100.00 100.00
 5 FUEL TIME ( SEC )                  54.40  59.60  60.20  61.30  62.60  61.20
 6 FUEL TEMPERATURE ( C )             26.00  26.00  26.00  26.00  26.00  26.00
 7 AIR METER READING                  34.00  36.00  37.20  40.30  44.10  53.60
 9 AIR METER DEPRESSION (mm.Hg)        1.20   1.27   1.32   1.46   1.58   1.93
 8 AIR METER TEMPERATURE ( C )        24.00  24.00  25.00  25.00  25.00  24.00
12 HYDROCARBONS ( PPMC )             -1200.0 -900.0-1050.0-1380.0-1800.0-3300.0
13 CARBON MONOXIDE ( % )              1.600   .140   .140   .130   .120   .190
14 OXIDES OF NITROGEN ( PPM )        -530.0 -730.0 -780.0 -370.0 -135.0  -18.0
15 CARBON DIOXIDE ( % )              13.800 13.400 12.700 11.300 10.100  7.800
16 OXYGEN ( % )                        .350  2.000  3.100  5.000  7.100  9.900
28 IGNITION TIMING                    17.00  21.00  23.00  25.00  30.00  39.00
26 EXHAUST TEMPERATURE                438.0  442.0  437.0  422.0  413.0  393.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-435.00-420.00-412.50-393.75-363.75-300.00
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                    40REV/S 2.5BAR

                                MIXTURE LOOP                                         REFER TO FIGS. 29-31

        DATE  8/ 9/82     TEST NO. 38.0     BAROMETER 767.80 MM.HG        WET BULB TEMP(C) 17.5
        RELATIVE HUMIDITY                = 69.41                          DRY BULB TEMP(C) 21.2
        HUMIDITY CORRECTION FACTOR       =   .95
        GRAINS OF WATER/LB DRY AIR       = 75.54

                       :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                       : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                       :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                          RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA
SPEED    POWER     BMEP     TORQUE    FUEL      VOLUMETRIC       AIR FUEL     B.T.E.     H C       NOX        C O        CO2      HC + NOX
REV/S     KW       BAR       N.M    G/KW.HR   EFFICIENCY(%)       RATIO         %      G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR    G/KW.HR

 40.0     7.24     2.50     28.80    914.4    32.5( 32.6)       6.2(  6.2)    19.75     4.59      5.12      82.25    1114.59      9.72
 40.0     7.24     2.50     28.80    834.6    33.9( 34.5)       7.0(  7.2)    21.63     3.51      7.35       7.48    1125.43     10.85
 40.0     7.24     2.50     28.80    826.3    35.6( 35.5)       7.4(  7.4)    21.85     4.22      8.28       7.80    1111.56     12.49
 40.0     7.24     2.50     28.80    811.4    38.7( 38.5)       8.2(  8.2)    22.25     5.95      4.26       7.95    1086.19     10.21
 40.0     7.24     2.50     28.80    794.6    42.7( 42.1)       9.3(  9.1)    22.72     8.28      1.68       7.99    1056.59      9.96
 40.0     7.24     2.50     28.80    812.8    52.9( 51.3)      11.3( 10.9)    22.21    18.63       .28      16.13    1040.39     18.90
 40REV/S 5.5BAR

          MIXTURE LOOP
                                                                                 REFER TO FIGS. 32-34
                                     BN60Y

BORE       STROKE      NUMBER OF      CYCLE      BRAKE      AIR METER      FUEL      H/CARBON   CALORIFIC   TURBOCHARGED
                       CYLINDERS      TYPE      CONSTANT    CONSTANT       S.G.       RATIO       VALUE       OPTION
79.50        73.00       4             4.          9.0640     .000281      .8180       4.00     19940.00        0

 DAY       MONTH          YEAR         TEST      BAROMETER   WET BULB     DRY BULB    POWER       FRICTION        OUTPUT
                                      NUMBER                TEMPERATURE  TEMPERATURE CORRECTION    OPTION         OPTION
 10          9             82         40.00      767.30      20.20        24.80        0           1.              4


 1 ENGINE SPEED (REV/S)            40.00  40.00  40.00  40.00  40.00  40.00
 2 BRAKE LOAD                       3.60   3.60   3.60   3.60   3.60   3.60
 3 FUEL MASS ( GRAMS )            150.00 150.00 150.00 150.00 150.00 150.00
 5 FUEL TIME ( SEC )               53.68  56.70  57.80  59.40  60.40  59.90
 6 FUEL TEMPERATURE ( C )          26.00  26.00  26.00  28.00  28.00  28.00
 7 AIR METER READING               55.00  57.70  60.40  65.50  71.00  81.90
 9 AIR METER DEPRESSION (mm.Hg)     1.97   2.08   2.19   2.37   2.57   2.99
 8 AIR METER TEMPERATURE ( C )     29.00  28.00  28.00  28.00  27.00  27.00
12 HYDROCARBONS ( PPMC )         -1020.0 -900.0 -990.0-1275.0-1560.0-2190.0
13 CARBON MONOXIDE ( % )           1.500   .200   .100   .110   .110   .130
14 OXIDES OF NITROGEN ( PPM )     -820.0-1220.0-1150.0 -780.0 -290.0  -78.0
15 CARBON DIOXIDE ( % )           13.900 13.600 12.800 11.400  9.700  8.400
16 OXYGEN ( % )                     .400  1.900  3.200  5.000  6.900  9.000
28 IGNITION TIMING                 17.00  22.00  24.00  27.00  29.00  34.00
26 EXHAUST TEMPERATURE             508.0  509.0  496.0  477.0  462.0  440.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-270.00-247.50-232.50-198.75-157.50 -82.50
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               40REV/S 5.5BAR
                                                                               REFER TO FIGS. 32-34
                        MIXTURE LOOP

      DATE 10/ 9/82     TEST NO. 40.0    BAROMETER 767.30 MM.HG     WET BULB TEMP(C) 20.2
      RELATIVE HUMIDITY              = 65.61                        DRY BULB TEMP(C) 24.8
      HUMIDITY CORRECTION FACTOR =    .97
      GRAINS OF WATER/LB DRY AIR   = 89.09

                 ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                 : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                 ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                   RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA
SPEED   POWER    BMEP   TORQUE   FUEL     VOLUMETRIC        AIR FUEL     B.T.E.    H C       NOX      C O       CO2      HC + NOX
REV/S    KW      BAR     N.M    G/KW.HR  EFFICIENCY(%)       RATIO         %     G/KW.HR  G/KW.HR  G/KW.HR   G/KW.HR   G/KW.HR
40.0    15.89    5.48   63.21    633.2    50.7( 51.9)      6.2(  6.4)   28.51    2.71     5.92    53.48    778.61      8.63
40.0    15.89    5.48   63.21    599.5    53.8( 54.6)      7.0(  7.1)   30.12    2.48     9.06     7.54    805.09     11.54
40.0    15.89    5.48   63.21    588.1    56.5( 57.2)      7.5(  7.6)   30.70    2.82     8.90     3.95    794.11     11.72
40.0    15.89    5.48   63.21    572.2    60.6( 62.0)      8.2(  8.4)   31.55    3.86     6.49     4.72    768.29     10.35
40.0    15.89    5.48   63.21    562.7    67.3( 67.3)      9.3(  9.3)   32.08    5.27     2.69     5.42    750.31      7.96
40.0    15.89    5.48   63.21    567.4    77.8( 77.6)     10.7( 10.7)   31.82    8.31      .82     7.34    745.41      9.13
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60REV/S 4.0BAR

          MIXTURE LOOP
                                                                                      REFER TO FIGS. 35-37
                          BN60Y

BORE       STROKE     NUMBER OF       CYCLE       BRAKE     AIR METER       FUEL      H/CARBON   CALORIFIC   TURBOCHARGED
                      CYLINDERS       TYPE       CONSTANT    CONSTANT       S.G.       RATIO       VALUE        OPTION
79.50        73.00       4             4.          9.0640     .000281       .8180       4.00     19940.00        0

 DAY       MONTH          YEAR        TEST      BAROMETER    WET BULB     DRY BULB     POWER        FRICTION        OUTPUT
                                     NUMBER                TEMPERATURE  TEMPERATURE  CORRECTION      OPTION         OPTION
 13          9             82        42.00       770.90      19.50        26.00        0             1.             4


 1 ENGINE SPEED (REV/S)              60.00  60.00  60.00  60.00  60.00  60.00
 2 BRAKE LOAD                         2.63   2.63   2.63   2.63   2.63   2.63
 3 FUEL MASS ( GRAMS )              200.00 200.00 200.00 200.00 200.00 200.00
 5 FUEL TIME ( SEC )                 58.20  61.30  61.70  62.70  63.50  62.20
 6 FUEL TEMPERATURE ( C )            24.00  23.00  24.00  26.00  24.00  26.00
 7 AIR METER READING                 61.00  70.50  73.30  80.00  87.00 105.00
 9 AIR METER DEPRESSION (mm.Hg)       2.24   2.41   2.53   2.77   3.02   3.77
 8 AIR METER TEMPERATURE ( C )       24.00  24.00  24.00  25.00  25.00  25.00
12 HYDROCARBONS ( PPMC )            -990.0 -870.0 -990.0-1290.0-1710.0-2700.0
13 CARBON MONOXIDE ( % )             1.100   .135   .130   .130   .120   .170
14 OXIDES OF NITROGEN ( PPM )       -850.0-1150.0-1050.0 -660.0 -220.0  -30.0
15 CARBON DIOXIDE ( % )             13.900 13.400 12.700 11.500 10.300  8.600
16 OXYGEN ( % )                       .400  2.200  3.150  5.000  6.900  9.300
28 IGNITION TIMING                   18.00  23.00  25.00  29.00  31.00  37.00
26 EXHAUST TEMPERATURE               563.0  555.0  545.0  524.0  500.0  471.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-363.75-337.50-330.00-303.75-270.00-195.00
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          60REV/S 4.0BAR                                                REFER TO FIGS. 35-37

                         MIXTURE LOOP

     DATE 13/ 9/82     TEST NO. 42.0    BAROMETER 770.90 MM.HG      WET BULB TEMP(C) 19.5
                                                                    DRY BULB TEMP(C) 26.0
     RELATIVE HUMIDITY            = 54.20
     HUMIDITY CORRECTION FACTOR   =   .96
     GRAINS OF WATER/LB DRY AIR   = 78.46

                   ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                   : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                   ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                     RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER     BMEP     TORQUE    FUEL     VOLUMETRIC        AIR FUEL       B.T.E.     H C       NOX       C O       CO2      HC + NOX
REV/S    KW       BAR       N.M    G/KW.HR  EFFICIENCY(%)        RATIO           %      G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

60.0    17.41     4.00     46.18    710.6    41.3( 38.9)       6.3(  5.9)    25.41      3.02      6.44     45.19    897.15       9.45
60.0    17.41     4.00     46.18    674.7    44.2( 44.9)       7.1(  7.2)    26.76      2.74      9.32      5.84    910.36      12.06
60.0    17.41     4.00     46.18    670.3    46.1( 46.7)       7.5(  7.6)    26.94      3.23      8.87      5.88    902.94      12.10
60.0    17.41     4.00     46.18    659.6    50.1( 50.8)       8.2(  8.3)    27.37      4.46      6.09      6.36    884.11      10.55
60.0    17.41     4.00     46.18    651.3    55.1( 55.3)       9.1(  9.2)    27.72      6.35      2.20      6.43    867.40       8.56
60.0    17.41     4.00     46.18    664.9    65.6( 66.6)      10.7( 10.8)    27.15     11.64       .35     10.88    864.61      12.00
```

MIXTURE DISTRIBUTION CHECKS - REFER TO FIG. 38

FULL LOAD

SPEED (rev/s)	CO (%)				
	CYL.1	CYL.2	CYL.3	CYL.4	T/P
20	9.4	0.3	0.4	9.3	5.0
40	4.0	1.2	2.2	6.6	3.7
60	4.4	3.3	3.4	8.2	5.7
80	3.0	5.0	5.3	7.8	5.4

PART LOAD

Rev/s/bar	O_2 (%)				
20/1.5	6.8	7.1	7.8	8.9	7.6
40/2.5	7.0	7.0	7.0	7.6	7.0
40/5.5	6.7	6.8	7.7	7.9	6.8
60/4.0	6.3	7.25	7.8	8.0	6.8

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NAT

      BEST FUELLING

                    BN60Y                                                  REFER TO FIGS. 39-43.

BORE      STROKE     NUMBER OF      CYCLE      BRAKE     AIR METER     FUEL     H/CARBON   CALORIFIC   TURBOCHARGED
                     CYLINDERS      TYPE      CONSTANT   CONSTANT      S.G.      RATIO       VALUE        OPTION
79.50      73.00        4            4.        9.0640     .000281      .8180      4.00      19940.00        0

DAY       MONTH        YEAR        TEST      BAROMETER    WET BULB     DRY BULB     POWER      FRICTION     OUTPUT
                                  NUMBER                TEMPERATURE  TEMPERATURE  CORRECTION    OPTION      OPTION
24          8           82        29.00       764.10       17.50        23.00          0           1.          4

 1 ENGINE SPEED (REV/S)
 2 BRAKE LOAD                       20.00  20.00  20.00  20.00  40.00  40.00  40.00  40.00  60.00  60.00  60.00  60.00
 3 FUEL MASS ( GRAMS )                .98   1.64   2.63   3.60    .98   1.64   2.63   3.60   1.64   2.63   3.60   4.60
 5 FUEL TIME ( SEC )                50.00  50.00  50.00  50.00 100.00 100.00 100.00 100.00 150.00 150.00 150.00 200.00
 6 FUEL TEMPERATURE ( C )           79.60  63.20  48.90  39.75  78.50  64.35  49.00  40.10  60.85  47.70  39.40  43.60
 7 AIR METER READING                27.00  26.00  26.00  26.00  24.00  25.00  25.00  25.00  25.00  25.00  24.00  23.00
 9 AIR METER DEPRESSION (mm.Hg)     18.00  23.00  30.30  37.60  37.30  46.30  61.50  75.10  75.60  96.70 113.00 120.00
 8 AIR METER TEMPERATURE ( C )        .79    .96   1.22   1.47   1.47   1.80   2.35   2.87   2.87   3.67   4.28   4.56
12 HYDROCARBONS ( PPMC )            24.00  25.00  25.00  26.00  26.00  27.00  27.00  27.00  30.00  29.00  31.00  30.00
13 CARBON MONOXIDE ( % )         -3600.0-2700.0-2295.0-1935.0-2700.0-2085.0-2010.0-1740.0-2280.0-2040.0-1485.0 -870.0
14 OXIDES OF NITROGEN ( PPM )        .150   .130   .120   .110   .140   .130   .110   .100   .120   .120   .100   .085
15 CARBON DIOXIDE ( % )             -26.0  -45.0  -56.0 -120.0  -38.0  -46.0  -60.0  -96.0  -55.0 -100.0 -165.0 -950.0
16 OXYGEN ( % )                     9.100  9.500  9.300  9.300  9.400  9.400  9.400  9.200  9.200  9.550  9.700 11.800
28 IGNITION TIMING                  8.000  8.000  8.000  7.900  8.000  8.100  8.100  8.000  7.900  8.000  7.400  5.100
26 EXHAUST TEMPERATURE              26.00  23.00  22.00  20.00  35.00  35.00  28.00  25.00  33.00  31.00  27.00  25.00
                                    264.0  285.0  317.0  343.0  370.0  394.0  424.0  446.0  463.0  479.0  509.0  560.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-393.75-311.25-187.50 -71.25-420.00-341.25-225.00-112.50-333.75-225.00-135.00 -90.00
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               MAP                                                                   REFER TO FIGS. 39-43

                           BEST FUELLING

     DATE 24/ 8/82      TEST NO. 29.0     BAROMETER 764.10 MM.HG      WET BULB TEMP(C) 17.5
                                                                      DRY BULB TEMP(C) 23.0
     RELATIVE HUMIDITY           = 57.90
     HUMIDITY CORRECTION FACTOR  =  1.02
     GRAINS OF WATER/LB DRY AIR  = 70.56

                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

   SPEED   POWER     BMEP    TORQUE    FUEL     VOLUMETRIC      AIR FUEL     B.T.E.     H C       NOX       C O       CO2     HC + NOX
   REV/S    KW       BAR      N.M    G/KW.HR  EFFICIENCY(%)      RATIO         %     G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

   20.0     2.16     1.49    17.21   1045.7    35.4( 34.5)      9.8(  9.5)   17.26    23.12       .45     14.18   1351.27     23.56
   20.0     3.62     2.50    28.80    787.0    44.6( 43.9)      9.7(  9.6)   22.94    12.77       .58      8.99   1032.33     13.35
   20.0     5.80     4.00    46.18    634.3    58.4( 57.9)      9.9(  9.8)   28.46     8.95       .60      6.87    836.25      9.55
   20.0     7.94     5.48    63.21    570.1    72.1( 71.6)      9.9(  9.8)   31.67     6.82      1.17      5.69    755.68      7.99
   40.0     4.32     1.49    17.21   1060.4    36.2( 35.5)      9.8(  9.6)   17.03    17.34       .67     13.16   1388.85     18.01
   40.0     7.24     2.50    28.80    773.0    44.8( 44.0)      9.9(  9.7)   23.36     9.84       .61      8.99   1021.04     10.45
   40.0    11.61     4.00    46.18    633.0    58.9( 58.4)      9.9(  9.8)   28.52     7.79       .65      6.25    838.64      8.44
   40.0    15.89     5.48    63.21    565.1    72.5( 71.2)     10.0(  9.8)   31.95     6.15       .95      5.20    751.44      7.10
   60.0    10.86     2.50    28.80    817.4    47.7( 47.4)      9.8(  9.8)   22.09    11.56       .81      8.94   1077.48     12.37
   60.0    17.41     4.00    46.18    650.3    60.3( 60.7)      9.8(  9.9)   27.76     8.01      1.12      6.88    860.74      9.13
   60.0    23.83     5.48    63.21    575.1    71.7( 70.6)      9.6(  9.4)   31.39     5.13      1.68      5.04    768.28      6.81
   60.0    30.45     7.00    80.77    542.3    74.3( 75.1)      8.3(  8.3)   33.29     2.44      7.77      3.36    733.22     10.21
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 20REV/S
                                                                                    REFER TO FIGS. 47-51.
           MAP

                                   BN60Y

BORE       STROKE      NUMBER OF       CYCLE      BRAKE       AIR METER      FUEL       H/CARBON    CALORIFIC   TURBOCHARGED
                       CYLINDERS       TYPE      CONSTANT     CONSTANT       S.G.        RATIO        VALUE        OPTION
79.50       73.00          4            4.        9.0640      .000000       .8180        4.00       19940.00          0

 DAY        MONTH         YEAR         TEST      BAROMETER    WET BULB      DRY BULB     POWER       FRICTION       OUTPUT
                                      NUMBER                 TEMPERATURE   TEMPERATURE  CORRECTION    OPTION        OPTION
 21          10            82         58.00        757.70      17.00         21.00         0           1.             4


 1 ENGINE SPEED (REV/S)             20.00  20.00  20.00  20.00  20.00
 2 BRAKE LOAD                         .98   1.64   2.63   3.60   4.60
 3 FUEL MASS ( GRAMS )              50.00  50.00  50.00  50.00  50.00
 5 FUEL TIME ( SEC )                79.60  62.20  46.80  38.00  31.40
 6 FUEL TEMPERATURE ( C )           22.00  21.00  23.00  20.00  23.00
 8 AIR METER TEMPERATURE ( C )      23.00  22.00  23.00  23.00  23.00
12 HYDROCARBONS ( PPMC )          -2160.0-1890.0-1695.0-1410.0-1080.0
13 CARBON MONOXIDE ( % )             .130   .120   .110   .100   .085
14 OXIDES OF NITROGEN ( PPM )      -130.0 -250.0 -450.0 -720.0-1150.0
15 CARBON DIOXIDE ( % )            11.500 11.000 11.200 11.300 12.800
16 OXYGEN ( % )                     5.100  5.100  4.900  4.900  2.900
28 IGNITION TIMING                  24.00  21.00  17.00  15.00  11.00
26 EXHAUST TEMPERATURE              255.0  284.0  327.0  358.0  404.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-427.50-341.25-240.00-127.50 -60.00
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             20REV/S
                                                                    REFER TO FIGS. 47-51.
                        MAP

       DATE 21/10/82     TEST NO. 58.0    BAROMETER 757.70 MM.HG     WET BULB TEMP(C) 17.0
                                                                     DRY BULB TEMP(C) 21.0
       RELATIVE HUMIDITY            = 67.09
       HUMIDITY CORRECTION FACTOR   =   .89
       GRAINS OF WATER/LB DRY AIR   = 73.04

                        :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                        : IF POWER * 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                        :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                          RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER    BMEP    TORQUE   FUEL     VOLUMETRIC          AIR FUEL         B.T.E.    H C      NOX      C O       CO2     HC + NOX
REV/S    KW      BAR      N.M    G/KW.HR  EFFICIENCY(%)          RATIO            %     G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR   G/KW.HR

20.0     2.16    1.49    17.21   1045.7    29.8(    .0)        8.2(    .0)      17.26    11.74     1.84     9.99  1389.05    13.58
20.0     3.62    2.50    28.80    799.7    38.5(    .0)        8.3(    .0)      22.58     8.16     2.78     7.39  1064.86    10.94
20.0     5.80    4.00    46.18    662.8    50.8(    .0)        8.2(    .0)      27.24     6.00     4.15     5.54   885.56    10.14
20.0     7.94    5.48    63.21    596.3    62.6(    .0)        8.2(    .0)      30.28     4.47     5.95     4.51   800.04    10.43
20.0    10.15    7.00    80.77    564.8    68.1(    .0)        7.4(    .0)      31.97     2.96     8.07     3.22   762.88    11.02
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40REV/S

         MAP                                                                              REFER TO FIGS. 47-51.

                           BN60Y

BORE       STROKE      NUMBER OF        CYCLE       BRAKE      AIR METER       FUEL       H/CARBON     CALORIFIC    TURBOCHARGED
                       CYLINDERS         TYPE      CONSTANT     CONSTANT        S.G.        RATIO        VALUE         OPTION
79.50       73.00          4              4.        9.0640      .000000        .8180        4.00       19940.00         0

DAY        MONTH         YEAR           TEST      BAROMETER    WET BULB      DRY BULB       POWER       FRICTION       OUTPUT
                                       NUMBER                 TEMPERATURE   TEMPERATURE   CORRECTION     OPTION        OPTION
20          10            82           56.00       763.70        17.00         21.00          0            1.             4

 1 ENGINE SPEED (REV/S)                 40.00  40.00  40.00  40.00  40.00
 2 BRAKE LOAD                             .98   1.64   2.63   3.60   4.60
 3 FUEL MASS ( GRAMS )                 100.00 100.00 100.00 100.00 100.00
 5 FUEL TIME ( SEC )                    80.30  62.30  48.80  40.00  33.00
 6 FUEL TEMPERATURE ( C )               21.00  22.00  21.00  21.00  20.00
 8 AIR METER TEMPERATURE ( C )          23.00  24.00  25.00  25.00  26.00
12 HYDROCARBONS ( PPMC )              -1620.0-1410.0-1200.0-1020.0 -870.0
13 CARBON MONOXIDE ( % )                 .130   .120   .110   .100   .090
14 OXIDES OF NITROGEN ( PPM )          -220.0 -300.0 -540.0 -780.0-1000.0
15 CARBON DIOXIDE ( % )                11.500 11.300 11.100 11.400 11.500
16 OXYGEN ( % )                         4.900  5.000  5.000  5.000  4.800
28 IGNITION TIMING                      30.00  25.00  24.00  23.00  23.00
26 EXHAUST TEMPERATURE                  387.0  413.0  448.0  472.0  498.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-450.00-390.00-285.00-191.25 -97.50
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          40REV/S
                                                                    REFER TO FIGS. 47-51.
                    MAP

     DATE 20/10/82     TEST NO. 56.0    BAROMETER 763.70 MM.HG     WET BULB TEMP(C) 17.0
                                                                   DRY BULB TEMP(C) 21.0
     RELATIVE HUMIDITY            = 67.00
     HUMIDITY CORRECTION FACTOR   =    .95
     GRAINS OF WATER/LB DRY AIR   = 72.36

                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER     BMEP     TORQUE    FUEL     VOLUMETRIC         AIR FUEL        B.T.E.     H C       NOX       C O       CO2       HC + NOX
REV/S   KW        BAR      N.M       G/KW.HR  EFFICIENCY(%)       RATIO           %        G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

40.0     4.32     1.49     17.21     1036.6    29.2(     .0)      8.1(     .0)   17.42      8.78      3.10      9.96    1384.70     11.88
40.0     7.24     2.50     28.80      798.4    38.2(     .0)      8.2(     .0)   22.61      5.98      3.37      7.23    1069.34      9.35
40.0    11.61     4.00     46.18      635.6    49.2(     .0)      8.3(     .0)   28.40      4.12      4.99      5.38     853.61      9.11
40.0    15.89     5.48     63.21      566.5    59.8(     .0)      8.3(     .0)   31.87      3.07      6.30      4.26     763.32      9.37
40.0    20.30     7.00     80.77      537.4    72.1(     .0)      8.2(     .0)   33.60      2.47      7.74      3.62     725.97     10.21
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 60REV/S

         MAP                                                                                    REFER TO FIGS. 47-51.

                                BN60Y

BORE      STROKE     NUMBER OF      CYCLE      BRAKE     AIR METER      FUEL      H/CARBON   CALORIFIC   TURBOCHARGED
                     CYLINDERS      TYPE     CONSTANT     CONSTANT      S.G.        RATIO      VALUE        OPTION
79.50      73.00         4           4.        9.0640     .000000      .8180        4.00     19940.00         0

 DAY      MONTH        YEAR         TEST     BAROMETER    WET BULB     DRY BULB     POWER      FRICTION      OUTPUT
                                   NUMBER               TEMPERATURE  TEMPERATURE  CORRECTION    OPTION       OPTION
 21        10           82         57.00      759.50       17.50        22.00        0           1.            4

 1 ENGINE SPEED (REV/S)                60.00  60.00  60.00  60.00
 2 BRAKE LOAD                           1.64   2.63   3.60   4.60
 3 FUEL MASS ( GRAMS )                150.00 150.00 150.00 150.00
 5 FUEL TIME ( SEC )                   61.00  47.40  39.40  33.10
 6 FUEL TEMPERATURE ( C )              18.00  21.00  17.00  16.00
 8 AIR METER TEMPERATURE ( C )         22.00  22.00  20.00  20.00
12 HYDROCARBONS ( PPMC )             -1410.0-1260.0 -840.0 -630.0
13 CARBON MONOXIDE ( % )                .120   .115   .105   .090
14 OXIDES OF NITROGEN ( PPM )         -530.0 -620.0 -690.0 -870.0
15 CARBON DIOXIDE ( % )               11.300 11.200 11.300 11.300
16 OXYGEN ( % )                        5.000  5.100  5.000  4.900
28 IGNITION TIMING                     32.00  26.00  21.00  17.00
26 EXHAUST TEMPERATURE                 488.0  515.0  540.0  570.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-386.25-285.00-202.50 -86.25
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               60REV/S                                                  REFER TO FIGS. 47-51.

                               MAP

     DATE 21/10/82      TEST NO. 57.0    BAROMETER 759.50 MM.HG      WET BULB TEMP(C) 17.5
                                                                     DRY BULB TEMP(C) 22.0
     RELATIVE HUMIDITY              = 64.16
     HUMIDITY CORRECTION FACTOR     =   .87
     GRAINS OF WATER/LB DRY AIR     = 74.10

                       :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                       : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                       :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                         RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

 SPEED   POWER    BMEP    TORQUE   FUEL    VOLUMETRIC        AIR FUEL        B.T.E.    H C      NOX       C O      CO2     HC + NOX
 REV/S    KW      BAR      N.M   G/KW.HR  EFFICIENCY(%)        RATIO            %    G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR

 60.0    10.86    2.50    28.80   815.4    38.9(    .0)     8.2(    .0)    22.14     6.11     5.89     7.38  1092.13    12.00
 60.0    17.41    4.00    46.18   654.4    50.5(    .0)     8.3(    .0)    27.59     4.42     5.59     5.74   878.03    10.01
 60.0    23.83    5.48    63.21   575.1    60.2(    .0)     8.3(    .0)    31.39     2.59     5.30     4.59   775.98     7.89
 60.0    30.45    7.00    80.77   535.8    71.6(    .0)     8.3(    .0)    33.70     1.81     6.25     3.68   725.45     8.06
 40REV/S 2.5BAR

        EGR LOOP                                                                          REFER TO FIG.53.

                                BN60Y

BORE       STROKE     NUMBER OF      CYCLE      BRAKE      AIR METER     FUEL      H/CARBON    CALORIFIC    TURBOCHARGED
                      CYLINDERS      TYPE      CONSTANT    CONSTANT      S.G.       RATIO        VALUE         OPTION
79.50       73.00        4            4.        9.0640      .000281      .8180       4.00      19940.00          0

 DAY       MONTH        YEAR         TEST      BAROMETER   WET BULB     DRY BULB     POWER       FRICTION       OUTPUT
                                    NUMBER                TEMPERATURE  TEMPERATURE CORRECTION     OPTION        OPTION
 19          10          82         55.00       765.90       15.60        21.70        0            1.             4


 1 ENGINE SPEED (REV/S)               40.00   40.00   40.00   40.00   40.00   40.00   40.00   40.00
 2 BRAKE LOAD                          1.64    1.64    1.64    1.64    1.64    1.64    1.64    1.64
 3 FUEL MASS ( GRAMS )               100.00  100.00  100.00  100.00  100.00  100.00  100.00  100.00
 5 FUEL TIME ( SEC )                  61.70   62.90   63.40   63.30   60.30   61.50   61.00   61.00
 6 FUEL TEMPERATURE ( C )             21.00   21.00   22.00   22.00   22.00   22.00   22.00   21.00
 7 AIR METER READING                  39.00   38.50   38.70   39.00   36.00   35.70   35.20   34.70
 9 AIR METER DEPRESSION (mm.Hg)        1.40    1.40    1.40    1.40    1.28    1.25    1.27    1.27
 8 AIR METER TEMPERATURE ( C )        20.00   21.00   20.00   20.00   21.00   21.00   21.00   21.00
12 HYDROCARBONS ( PPMC )            -1500.0-1695.0-1830.0-1920.0-1050.0-1290.0-1350.0-1440.0
13 CARBON MONOXIDE ( % )               .115    .110    .110    .115    .125    .120    .115    .120
14 OXIDES OF NITROGEN ( PPM )        -290.0  -135.0   -62.0   -58.0  -660.0  -320.0  -160.0  -160.0
15 CARBON DIOXIDE ( % )              11.400  11.300  11.000  11.000  12.800  12.800  12.900  13.200
16 OXYGEN ( % )                       5.000   5.100   5.300   5.400   2.900   2.900   2.900   2.800
28 IGNITION TIMING                    25.00   28.00   28.00   30.00   22.00   25.00   26.00   28.00
26 EXHAUST TEMPERATURE                415.0   409.0   406.0   405.0   429.0   422.0   421.0   418.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-390.00-367.50-345.00-337.50-408.75-390.00-371.25-371.25
   CO2 INLET (NO EGR)                   .06     .06     .05     .06     .05     .06     .05     .05
   CO2 INLET (WITH EGR)                 .06     .50     .94    1.00     .05     .62    1.20    1.30
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                  40REV/S 2.5BAR                                          REFER TO FIG.53.

                               EGR LOOP

        DATE 19/10/82      TEST NO. 55.0    BAROMETER 765.90 MM.HG      WET BULB TEMP(C) 15.6
                                                                        DRY BULB TEMP(C) 21.7
        RELATIVE HUMIDITY            = 52.29
        HUMIDITY CORRECTION FACTOR   =   .89
        GRAINS OF WATER/LB DRY AIR   = 58.58

                       :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                       : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                       :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                         RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER     BMEP     TORQUE   FUEL     VOLUMETRIC       AIR FUEL        B.T.E.     H C       NOX       C O       CO2     HC + NOX
REV/S    KW       BAR       N.M    G/KW.HR  EFFICIENCY(%)      RATIO            %      G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

40.0     7.24     2.50     28.80    806.2    37.8( 37.7)     8.2(   8.2)     22.39      6.38      3.14      6.93   1079.39      9.52
40.0     7.24     2.50     28.80    790.8    37.4( 37.1)     8.3(   8.2)     22.83      7.10      1.46      6.55   1056.86      8.57
40.0     7.24     2.50     28.80    784.6    37.5( 37.4)     8.4(   8.4)     23.01      7.76       .67      6.66   1046.31      8.43
40.0     7.24     2.50     28.80    785.8    37.7( 37.7)     8.4(   8.4)     22.98      8.15       .63      6.96   1046.49      8.78
40.0     7.24     2.50     28.80    824.9    34.8( 34.7)     7.4(   7.3)     21.89      4.19      6.71      6.91   1111.16     10.89
40.0     7.24     2.50     28.80    808.8    34.0( 34.5)     7.3(   7.4)     22.32      5.03      3.19      6.49   1087.38      8.22
40.0     7.24     2.50     28.80    815.4    34.3( 34.0)     7.3(   7.3)     22.14      5.28      1.59      6.22   1096.24      6.87
40.0     7.24     2.50     28.80    815.4    34.0( 33.5)     7.3(   7.2)     22.14      5.52      1.56      6.34   1095.38      7.08
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         MAP AUTO IGN FUEL EGR                                                                         REFER TO FIGS. 54, 56-62.

                                   BN60Y

 BORE         STROKE      NUMBER OF        CYCLE        BRAKE      AIR METER       FUEL      H/CARBON   CALORIFIC   TURBOCHARGED
                          CYLINDERS        TYPE       CONSTANT      CONSTANT       S.G.       RATIO       VALUE        OPTION
 79.50         73.00          4             4.          9.0640       .000000       .8180       4.00     19940.00        0

 DAY          MONTH          YEAR          TEST       BAROMETER     WET BULB      DRY BULB     POWER      FRICTION         OUTPUT
                                          NUMBER                  TEMPERATURE   TEMPERATURE  CORRECTION    OPTION          OPTION
 25             11            82          77.00        756.70        13.50         19.00         0           1.              4


 1 ENGINE SPEED (REV/S)              40.00  40.00  40.00  40.00  40.00  60.00  60.00  60.00  60.00  80.00  80.00
 2 BRAKE LOAD                          .98   1.64   2.63   3.60   4.60   1.64   2.63   3.60   4.60   2.63   3.60
 3 FUEL MASS ( GRAMS )              100.00 100.00 100.00 100.00 100.00 150.00 150.00 150.00 150.00 200.00 200.00
 5 FUEL TIME ( SEC )                 79.80  63.30  49.00  39.80  33.30  61.30  47.60  38.70  31.90  44.10  36.20
 6 FUEL TEMPERATURE ( C )            18.00  18.00  18.00  18.00  18.00  17.00  17.00  17.00  16.00  18.00  17.00
 8 AIR METER TEMPERATURE ( C )       21.00  22.00  22.00  25.00  26.00  25.00  28.00  28.00  29.00  27.00  27.00
12 HYDROCARBONS ( PPMC )           -1650.0-1680.0-1710.0-1320.0 -900.0-1800.0-1260.0 -870.0 -810.0 -810.0 -630.0
13 CARBON MONOXIDE ( % )              .130   .110   .130   .110   .090   .150   .120   .110   .130   .135   .170
14 OXIDES OF NITROGEN ( PPM )       -150.0 -280.0 -100.0 -300.0 -700.0 -120.0 -330.0 -750.0 -950.0 -850.0-1000.0
15 CARBON DIOXIDE ( % )             10.800 10.700 11.000 11.500 11.000 11.200 12.000 12.600 12.700 13.800 13.300
16 OXYGEN ( % )                      5.300  5.800  5.300  4.800  5.500  4.700  4.300  3.500  3.200  2.400  2.100
28 IGNITION TIMING                   29.00  28.00  25.00  19.00  16.00  34.00  31.00  28.00  23.00  34.00  30.00
26 EXHAUST TEMPERATURE               390.0  402.0  422.0  449.0  493.0  466.0  500.0  543.0  576.0  570.0  606.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-435.00-356.25-202.50-120.00 -45.00-326.25-240.00-165.00 -93.75-266.25-180.00
   CO2 INLET (NO EGR)                  .05    .05    .05    .06    .05    .06    .05    .05    .05    .05    .06
   CO2 INLET (WITH EGR)                .15    .18   1.10    .80    .20   1.20   1.05    .90    .55    .85    .83
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                      MAP AUTO IGN FUEL EGR                        REFER TO FIGS. 54, 56-62.

   DATE 25/11/82     TEST NO. 77.0    BAROMETER 756.70 MM.HG      WET BULB TEMP(C) 13.5
                                                                  DRY BULB TEMP(C) 19.0
   RELATIVE HUMIDITY            = 53.60
   HUMIDITY CORRECTION FACTOR   =  1.01
   GRAINS OF WATER/LB DRY AIR   = 51.37

                        ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                        : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                        ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                          RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER    BMEP    TORQUE    FUEL    VOLUMETRIC         AIR FUEL       B.T.E.     H C       NOX       C O       CO2      HC + NOX
REV/S    KW      BAR      N.M    G/KW.HR  EFFICIENCY(%)        RATIO           %      G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR    G/KW.HR

40.0     4.32    1.49    17.21   1043.1    30.4(    .0)      8.4(    .0)     17.31     9.45      2.25     10.65    1390.70     11.69
40.0     7.24    2.50    28.80    785.8    39.4(    .0)      8.6(    .0)     22.98     7.31      3.24      6.86    1048.94     10.55
40.0    11.61    4.00    46.18    633.0    49.4(    .0)      8.4(    .0)     28.52     5.85       .91      6.35     843.80      6.76
40.0    15.89    5.48    63.21    569.3    59.8(    .0)      8.1(    .0)     31.71     3.94      2.49      4.65     764.21      6.43
40.0    20.30    7.00    80.77    532.5    75.1(    .0)      8.5(    .0)     33.90     2.62      5.74      3.74     718.70      8.36
60.0    10.86    2.50    28.80    811.4    38.6(    .0)      8.1(    .0)     22.25     7.76      1.44      9.20    1079.25      9.20
60.0    17.41    4.00    46.18    651.6    49.0(    .0)      7.9(    .0)     27.71     4.17      3.19      5.57     875.22      7.35
60.0    23.83    5.48    63.21    585.5    57.9(    .0)      7.6(    .0)     30.83     2.50      6.32      4.39     790.82      8.81
60.0    30.45    7.00    80.77    555.9    69.5(    .0)      7.5(    .0)     32.48     2.19      7.70      4.89     750.19      9.89
80.0    23.21    4.00    46.18    703.3    47.7(    .0)      7.2(    .0)     25.67     2.60      7.89      5.92     950.03     10.49
80.0    31.77    5.48    63.21    626.0    57.6(    .0)      7.1(    .0)     28.84     1.85      8.50      6.87     844.27     10.36
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          MAP AUTO IGN FUEL EGR                                    REFER TO FIGS. 54, 56-62

                                  BN60Y

  BORE        STROKE       NUMBER OF        CYCLE       BRAKE      AIR METER       FUEL       H/CARBON    CALORIFIC    TURBOCHARGED
                           CYLINDERS         TYPE      CONSTANT     CONSTANT        S.G.        RATIO        VALUE         OPTION
 79.50         73.00           4              4.         9.0640     .000000        .8180        4.00       19940.00          0

  DAY         MONTH          YEAR          TEST      BAROMETER    WET BULB      DRY BULB      POWER       FRICTION        OUTPUT
                                          NUMBER                 TEMPERATURE  TEMPERATURE   CORRECTION     OPTION          OPTION
  26            11            82          79.00       753.00        14.00        20.50          0            1.               4


   1 ENGINE SPEED (REV/S)               50.00  50.00  50.00  50.00  50.00  50.00  30.00  30.00  30.00  30.00  60.00  60.00  70.00
 70.00  70.00  70.00  70.00  80.00  80.00
   2 BRAKE LOAD                          1.10   1.64   1.97   2.63   3.60   4.60    .98   1.64   2.63   3.60   1.31   1.97   1.64
  1.97   2.63   3.60   4.60   4.27   4.60
   3 FUEL MASS ( GRAMS )               100.00 100.00 100.00 100.00 100.00 100.00  50.00  50.00  50.00  50.00 150.00 150.00 200.00
200.00 200.00 200.00 200.00 200.00 250.00
   5 FUEL TIME ( SEC )                  60.80  50.30  46.20  39.40  32.00  26.10  52.60  41.30  31.50  26.20  67.20  57.40  68.80
 63.40  53.00  42.90  36.40  32.40  38.00
   6 FUEL TEMPERATURE ( C )             16.00  17.00  17.00  16.00  16.00  16.00  16.00  17.00  17.00  17.00  18.00  16.00  16.00
 16.00  15.00  15.00  15.00  14.00  14.00
   8 AIR METER TEMPERATURE ( C )        18.00  17.00  21.00  20.00  21.00  23.00  24.00  20.00  20.00  22.00  18.00  19.00  23.00
 22.00  24.00  29.00  32.00  26.00  29.00
  12 HYDROCARBONS ( PPMC )           -1980.0-1560.0-1920.0-1695.0-1290.0 -870.0-2460.0-1830.0-1770.0-1500.0-2100.0-1710.0-1620.0
1470.0 -990.0 -870.0 -990.0 -810.0 -840.0
  13 CARBON MONOXIDE ( % )               .140   .130   .130   .130   .110   .150   .150   .140   .120   .110   .140   .130   .130
  .130   .130   .120   .170   .160   .600
  14 OXIDES OF NITROGEN ( PPM )       -200.0 -320.0 -100.0 -190.0 -270.0 -940.0 -180.0 -330.0 -440.0 -280.0  -82.0 -160.0 -170.0
-250.0 -570.0 -890.0 -940.0 -950.0-1000.0
  15 CARBON DIOXIDE ( % )              10.800 11.200 11.300 11.500 11.100 11.900 10.700 11.000 10.600 11.400 11.800 12.200 12.400
12.400 13.300 13.700 13.700 13.800 13.400
  16 OXYGEN ( % )                       5.600  5.200  4.800  4.500  5.000  3.500  5.800  5.200  6.100  5.300  4.800  4.300  4.100
 4.000  2.900  2.400  2.400 21.000  2.400
  28 IGNITION TIMING                    32.00  32.00  31.00  28.00  23.00  20.00  25.00  25.00  22.00  15.00  34.00  34.00  36.00
 36.00  34.00  30.00  25.00  26.00  24.00
  26 EXHAUST TEMPERATURE                430.0  442.0  443.0  462.0  494.0  531.0  375.0  361.0  386.0  415.0  450.0  467.0  497.0
 512.0  549.0  580.0  608.0  632.0  638.0
  11 INTAKE MANIFOLD PRESS.(mm.Hg)-420.00-367.50-296.25-232.50-138.75 -90.00-431.25-352.50-232.50-123.75-360.00-315.00-337.50
315.00-266.25-191.25-112.50-127.50-105.00
 CO2 INLET (NO EGR)
                                          .05
  .07    .06    .06    .06    .06         .06    .05    .05    .05    .05    .06    .05    .06    .06    .05    .06    .06    .06
 CO2 INLET (WITH EGR)
                                          .11
 1.15   1.05    .70    .65    .70         .50    .31   1.11   1.95    .75    .38    .15    .15    .12    .60   1.34   .130   1.25
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          20REV/S

                    MAP AUTO IGN FUEL EGR
                                                                      REFER TO FIGS. 54, 56-62

   DATE 26/11/82      TEST NO. 79.0     BAROMETER 753.00 MM.HG      WET BULB TEMP(C) 14.0
                                                                    DRY BULB TEMP(C) 20.5
   RELATIVE HUMIDITY              = 48.26
   HUMIDITY CORRECTION FACTOR  =  1.05
   GRAINS OF WATER/LB DRY AIR  = 51.01

                 ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                 : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                 ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                   RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER     BMEP    TORQUE    FUEL     VOLUMETRIC         AIR FUEL        B.T.E.    H C       NOX       C O        CO2      HC + NOX
REV/S    KW        BAR     N.M    G/KW.HR  EFFICIENCY(%)          RATIO            %     G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

50.0     6.07     1.67    19.32    975.8     32.1(     .0)      8.5(    .0)     18.50    10.56      2.68     10.68   1295.09     13.24
50.0     9.05     2.50    28.80    791.1     37.8(     .0)      8.3(    .0)     22.82     6.59      3.34      7.81   1056.74      9.93
50.0    10.87     3.00    34.59    717.0     40.7(     .0)      8.1(    .0)     25.18     7.27       .99      6.99    954.37      8.26
50.0    14.51     4.00    46.18    629.8     46.9(     .0)      8.0(    .0)     28.67     5.57      1.60      6.05    840.62      7.18
50.0    19.86     5.48    63.21    566.5     60.0(     .0)      8.3(    .0)     31.87     3.95      2.16      4.79    760.07      6.10
50.0    25.38     7.00    80.77    543.6     68.4(     .0)      7.6(    .0)     33.21     2.42      7.02      5.86    731.06      9.44
30.0     3.24     1.49    17.21   1055.0     31.7(     .0)      8.5(    .0)     17.11    14.20      2.84     12.41   1391.24     17.04
30.0     5.43     2.50    28.80    802.9     38.8(     .0)      8.3(    .0)     22.49     7.93      3.69      8.65   1067.97     11.61
30.0     8.70     4.00    46.18    656.5     53.5(     .0)      8.8(    .0)     27.50     6.47      4.17      6.30    874.39     10.64
30.0    11.92     5.48    63.21    576.6     61.6(     .0)      8.3(    .0)     31.31     4.56      2.26      4.74    772.33      6.82
60.0     8.67     1.99    23.00    926.7     34.3(     .0)      8.0(    .0)     19.48     9.90       .97      9.30   1231.54     10.87
60.0    13.04     3.00    34.59    721.4     39.3(     .0)      7.8(    .0)     25.03     6.15      1.45      6.54    964.16      7.60
70.0    12.67     2.50    28.80    826.3     37.6(     .0)      7.8(    .0)     21.85     6.59      1.86      7.38   1105.71      8.45
70.0    15.21     3.00    34.59    746.4     40.5(     .0)      7.7(    .0)     24.19     5.41      2.43      6.67   1000.36      7.84
70.0    20.31     4.00    46.18    668.8     46.3(     .0)      7.3(    .0)     26.99     3.11      4.88      5.61    901.72      7.99
70.0    27.80     5.48    63.21    603.7     56.8(     .0)      7.2(    .0)     29.91     2.41      7.44      4.55    815.73      9.85
70.0    35.53     7.00    80.77    556.8     67.4(     .0)      7.1(    .0)     32.43     2.52      7.70      5.91    748.88     10.22
80.0    37.69     6.50    74.98    589.6    117.0(     .0)     12.9(    .0)     30.62     2.18      7.10      5.87    795.03      9.28
80.0    40.60     7.00    80.77    583.4     68.9(     .0)      7.0(    .0)     30.95     2.22      8.00     21.70    761.39     10.22
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MIXTURE LOOP

        IGNITION LOOP
                                                            REFER TO FIGS. 65-71-
                          BN60Y

BORE      STROKE    NUMBER OF     CYCLE     BRAKE     AIR METER    FUEL     H/CARBON   CALORIFIC  TURBOCHARGED
                    CYLINDERS     TYPE     CONSTANT   CONSTANT     S.G.      RATIO      VALUE       OPTION
79.50      73.00        4          4.       9.0640     .000000     .8180      4.00     19940.00        0

 DAY      MONTH       YEAR        TEST     BAROMETER   WET BULB    DRY BULB    POWER      FRICTION      OUTPUT
                                 NUMBER               TEMPERATURE TEMPERATURE CORRECTION   OPTION       OPTION
 15         1          83        98.00     761.70      14.00       20.00        0           1.            4


 1 ENGINE SPEED (REV/S)              15.00  15.00  15.00  15.00  15.00  15.00  15.00  15.00  15.00  15.00  15.00  15.00
 2 BRAKE LOAD                          .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 3 FUEL MASS ( GRAMS )               20.00  20.00  20.00  20.00  20.00  20.00  20.00  20.00  20.00  20.00  20.00  20.00
 5 FUEL TIME ( SEC )                 56.90  68.70  69.00  59.20  65.40  72.20  69.50  66.00  74.80  70.80  70.00  71.50
 6 FUEL TEMPERATURE ( C )            16.00  17.00  17.00  17.00  17.00  19.00  19.00  18.00  19.00  19.00  19.00  19.00
 8 AIR METER TEMPERATURE ( C )       34.00  29.00  27.00  25.00  24.00  33.00  32.00  33.00  33.00  33.00  32.00  33.00
12 HYDROCARBONS ( PPMC )           -6150.0-3150.0-4500.0-4200.0-3150.0-3000.0-2850.0-2280.0-3450.0-3300.0-4500.0-3180.0
13 CARBON MONOXIDE ( % )             6.000  1.600   .800  4.800  2.800  1.800  1.800  1.600  1.600  1.600  1.700  1.600
14 OXIDES OF NITROGEN ( PPM )         -7.3   -8.4   -8.8   -7.0   -8.0   -9.0   -8.5   -8.6   -9.0   -9.0   -9.5   -7.5
15 CARBON DIOXIDE ( % )             10.500 13.400 13.000 11.300 12.400 13.000 12.900 13.100 12.700 12.600 12.500 12.600
16 OXYGEN ( % )                      1.500  1.200  2.100  1.100   .900  1.000  1.000   .800  1.300  1.200  1.400  1.100
28 IGNITION TIMING                   19.00  19.00  19.00  19.00  19.00  19.00  14.00   9.00  25.00  30.00  35.00  19.00
26 EXHAUST TEMPERATURE               137.0  137.0  137.0  137.0  137.0  137.0  153.0  157.0  148.0  140.0  137.0  138.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)-525.00-525.00-525.00-525.00-525.00-532.50-525.00-525.00-532.50-525.00-532.50-525.00
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           MIXTURE LOOP
                                                                      REFER TO FIGS. 65-71
                     IGNITION LOOP

    DATE 15/ 1/83      TEST NO. 98.0     BAROMETER 761.70 MM.HG      WET BULB TEMP(C) 14.0
                                                                     DRY BULB TEMP(C) 20.0
    RELATIVE HUMIDITY             = 51.01
    HUMIDITY CORRECTION FACTOR    =  1.19
    GRAINS OF WATER/LB DRY AIR    = 51.68

                      ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                      ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                         RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER    BMEP    TORQUE   FUEL      VOLUMETRIC        AIR FUEL       B.T.E.    H C       NOX       C O      CO2       HC + NOX
REV/S   KW       BAR     N.M      G/KW.HR   EFFICIENCY(%)     RATIO          %         G/KW.HR   G/KW.HR   G/KW.HR  G/KW.HR   G/KW.HR

15.0    .00      .00     .00      1265.4    14.8(    .0)      5.3(   .0)     .00       28.97     .13       384.01   1055.90   29.11
15.0    .00      .00     .00      1048.0    14.4(    .0)      6.3(   .0)     .00       13.87     .11        95.18   1252.52   13.98
15.0    .00      .00     .00      1043.5    15.2(    .0)      6.7(   .0)     .00       20.83     .12        50.79   1296.89   20.95
15.0    .00      .00     .00      1216.2    14.4(    .0)      5.5(   .0)     .00       19.81     .09       306.79   1134.81   19.91
15.0    .00      .00     .00      1100.9    14.0(    .0)      5.9(   .0)     .00       14.33     .10       172.75   1202.04   14.43
15.0    .00      .00     .00       997.2    13.7(    .0)      6.2(   .0)     .00       12.69     .13       103.37   1173.05   12.83
15.0    .00      .00     .00      1036.0    14.2(    .0)      6.2(   .0)     .00       12.61     .13       108.24   1218.87   12.73
15.0    .00      .00     .00      1090.9    15.0(    .0)      6.2(   .0)     .00       10.68     .14       101.81   1309.74   10.82
15.0    .00      .00     .00       962.6    13.4(    .0)      6.3(   .0)     .00       14.42     .13        91.37   1139.55   14.55
15.0    .00      .00     .00      1016.9    14.1(    .0)      6.3(   .0)     .00       14.67     .14        97.32   1204.24   14.80
15.0    .00      .00     .00      1028.6    14.2(    .0)      6.3(   .0)     .00       20.01     .14       103.51   1195.84   20.15
15.0    .00      .00     .00      1007.0    14.0(    .0)      6.3(   .0)     .00       14.01     .11        96.47   1193.70   14.12
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EPA 1.5L HRCC VW ENGINE

        13:1 CR                                                            REFER TO FIGS. 73-75.

                              FULL LOAD POWER CURVE         WITHOUT INTAKE HEATER.

BORE       STROKE     NUMBER OF      CYCLE      BRAKE      AIR METER      FUEL      H/CARBON   CALORIFIC   TURBOCHARGED
                      CYLINDERS      TYPE     CONSTANT     CONSTANT       S.G.       RATIO       VALUE        OPTION
79.50       73.00        4            4.        9.0640      .000000      .8180       4.00      19940.00        0

DAY        MONTH        YEAR        TEST     BAROMETER    WET BULB     DRY BULB      POWER      FRICTION       OUTPUT
                                   NUMBER                TEMPERATURE  TEMPERATURE  CORRECTION    OPTION        OPTION
12           1           83        93.00      772.15        14.00        19.50         1           1.            4

 1 ENGINE SPEED (REV/S)              20.00  30.00  40.00  50.00  60.00  70.00  80.00  90.00
 2 BRAKE LOAD                         5.38   6.10   6.38   6.53   6.55   6.40   6.08   5.55
 3 FUEL MASS ( GRAMS )              150.00 150.00 200.00 200.00 250.00 250.00 250.00 250.00
 5 FUEL TIME ( SEC )                 64.00  39.60  41.90  34.60  36.30  31.20  27.70  24.80
 6 FUEL TEMPERATURE ( C )            13.00  14.00  14.00  14.00  13.00  13.00  13.00  13.00
 8 AIR METER TEMPERATURE ( C )       27.00  25.00  26.00  28.00  26.00  27.00  30.00  33.00
12 HYDROCARBONS ( PPMC )          -2070.0-1740.0 -900.0 -960.0-1110.0-1200.0-1110.0-1080.0
13 CARBON MONOXIDE ( % )             6.400  6.300  4.800  3.400  2.900  2.900  2.900  3.600
14 OXIDES OF NITROGEN ( PPM )       -100.0 -105.0 -200.0 -500.0 -750.0 -890.0 -800.0 -670.0
15 CARBON DIOXIDE ( % )             11.000 10.900 11.900 12.700 13.000 12.900 13.000 12.500
16 OXYGEN ( % )                       .200   .200   .200   .300   .400   .500   .300   .300
28 IGNITION TIMING                   10.00  12.00  16.00  18.00  21.00  22.00  22.00  22.00
26 EXHAUST TEMPERATURE               406.0  444.0  509.0  578.0  616.0  644.0  665.0  668.0
11 INTAKE MANIFOLD PRESS.(mm.Hg)       .00    .00    .00    .00    .00    .00    .00    .00
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                                                                                    REFER TO FIGS. 73-75.
                         EPA 1.5L HRCC VW ENGINE          WITHOUT INTAKE HEATER.

                                  13:1 CR

      DATE 12/ 1/83     TEST NO. 93.0    BAROMETER 772.15 MM.HG      WET BULB TEMP(C) 14.0
                                                                     DRY BULB TEMP(C) 19.5
      RELATIVE HUMIDITY             = 53.88
      HUMIDITY CORRECTION FACTOR    =  1.23
      GRAINS OF WATER/LB DRY AIR    = 52.22

                         ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                         : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                         ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                           RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

      POWERS CORRECTED TO DIN.70020
      -----------------------------

   SPEED   POWER      RMEP    TORQUE   FUEL     VOLUMETRIC         AIR FUEL        B.T.E.    H C       NOX       C O       CO2      HC + NOX
   REV/S    KW        BAR      N.M    G/KW.HR  EFFICIENCY(%)         RATIO            %     G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR   G/KW.HR

   20.0    11.82      8.16     94.09   710.8    68.1(     .0)      5.0(     .0)    25.40     5.42       .78    225.15    608.02      6.20
   30.0    20.04      9.22    106.32   675.4    73.2(     .0)      5.1(     .0)    26.73     4.38       .74    213.55    580.53      5.12
   40.0    27.99      9.66    111.39   610.3    74.4(     .0)      5.4(     .0)    29.58     2.13      1.36    152.34    593.43      3.48
   50.0    35.94      9.92    114.39   577.7    77.0(     .0)      5.8(     .0)    31.25     2.23      3.50    105.87    621.34      5.73
   60.0    43.11      9.91    114.36   571.8    77.7(     .0)      5.9(     .0)    31.57     2.58      4.97     90.39    636.65      7.55
   70.0    49.23      9.70    111.93   583.6    78.0(     .0)      5.9(     .0)    30.93     2.86      6.20     92.77    648.36      9.06
   80.0    53.71      9.26    106.86   605.5    77.1(     .0)      5.9(     .0)    29.82     2.73      6.27     95.71    674.11      9.00
   90.0    55.43      8.50     98.03   658.5    75.2(     .0)      5.7(     .0)    27.42     2.85      6.24    127.66    696.48      9.09
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EPA 1.5L HRCC VW ENGINE
                                                                              REFER TO FIGS. 73-75
          13:1 CR WITH INTAKE HEATER FITTED

                              FULL LOAD POWER CURVE

BORE       STROKE     NUMBER OF     CYCLE      BRAKE      AIR METER     FUEL     H/CARBON   CALORIFIC  TURBOCHARGED
                      CYLINDERS      TYPE     CONSTANT    CONSTANT      S.G.      RATIO       VALUE       OPTION
79.50       73.00         4           4.        9.0640     .000000      .8180      4.00     19940.00        0

 DAY       MONTH        YEAR        TEST     BAROMETER    WET BULB     DRY BULB    POWER      FRICTION      OUTPUT
                                   NUMBER               TEMPERATURE TEMPERATURE CORRECTION    OPTION       OPTION
 13          1           83        94.00      765.75       13.00        21.00       1           1.            4

 1 ENGINE SPEED (REV/S)
 2 BRAKE LOAD                    20.00  30.00  40.00  50.00  60.00  70.00  80.00  90.00
 3 FUEL MASS ( GRAMS )             5.36   6.12   6.28   6.33   6.32   6.15   5.81   5.30
 5 FUEL TIME ( SEC )             150.00 150.00 200.00 200.00 250.00 250.00 250.00 250.00
 6 FUEL TEMPERATURE ( C )         65.00  43.00  45.10  36.50  38.10  32.90  29.30  26.10
 8 AIR METER TEMPERATURE ( C )    14.00  14.00  13.00  13.00  13.00  11.00  11.00  11.00
12 HYDROCARBONS ( PPMC )          24.00  22.00  21.00  22.00  23.00  24.00  26.00  25.00
13 CARBON MONOXIDE ( % )        -2100.0-1860.0-1200.0-1260.0-1380.0-1200.0-1080.0-1020.0
14 OXIDES OF NITROGEN ( PPM )      6.100  4.500  3.000  2.600  2.400  2.600  2.800  3.700
15 CARBON DIOXIDE ( % )          -150.0 -400.0 -720.0 -830.0 -920.0 -780.0 -760.0 -680.0
16 OXYGEN ( % )                  11.800 12.500 13.100 13.300 13.400 13.200 13.100 12.800
28 IGNITION TIMING                 .250   .200   .300   .400   .400   .400   .300   .300
26 EXHAUST TEMPERATURE            10.00  12.00  16.00  18.00  21.00  22.00  22.00  22.00
11 INTAKE MANIFOLD PRESS.(mm.Hg)  428.0  462.0  533.0  578.0  609.0  641.0  661.0  666.0
                                   .00    .00    .00    .00    .00    .00    .00    .00
```

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                    EPA 1.5L HRCC VW ENGINE
                                                                    REFER TO FIGS. 73-75
                                  13:1 CR WITH INTAKE HEATER FITTED

      DATE 13/ 1/83     TEST NO. 94.0    BAROMETER 765.75 MM.HG      WET BULB TEMP(C) 13.0
                                                                     DRY BULB TEMP(C) 21.0
      RELATIVE HUMIDITY              = 38.34
      HUMIDITY CORRECTION FACTOR     =  1.01
      GRAINS OF WATER/LB DRY AIR     = 41.00

                    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                       RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

      POWERS CORRECTED TO DIN.70020
      -----------------------------

   SPEED   POWER     BMEP    TORQUE    FUEL     VOLUMETRIC         AIR FUEL        B.T.E.    H C      NOX       C O       CO2     HC + NOX
   REV/S    KW       BAR      N.M    G/KW.HR  EFFICIENCY(%)         RATIO             %    G/KW.HR  G/KW.HR  G/KW.HR   G/KW.HR   G/KW.HR

   20.0    11.82     8.15    94.05    702.4    68.7(     .0)     5.2(    .0)    25.70     5.34     1.09    206.17    626.63     6.42
   30.0    20.17     9.28   107.02    620.0    73.0(     .0)     5.5(    .0)    29.12     4.39     2.53    141.49    617.55     6.92
   40.0    27.55     9.50   109.63    576.0    73.9(     .0)     5.8(    .0)    31.34     2.78     4.36     92.97    637.85     7.14
   50.0    34.77     9.60   110.69    564.9    74.7(     .0)     6.0(    .0)    31.96     2.89     5.11     79.96    642.68     8.00
   60.0    41.73     9.60   110.71    564.6    75.3(     .0)     6.0(    .0)    31.97     3.18     5.83     74.16    650.61     9.01
   70.0    47.46     9.35   107.91    576.0    74.5(     .0)     6.0(    .0)    31.35     2.82     5.17     82.08    654.72     8.00
   80.0    51.41     8.87   102.29    599.0    72.8(     .0)     5.9(    .0)    30.14     2.63     5.50     91.44    672.20     8.13
   90.0    52.67     8.07    93.15    655.2    70.1(     .0)     5.7(    .0)    27.55     2.63     5.09    127.47    692.87     7.72
```

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MAP

          AUTO FUEL IGN EGR
                                                                        REFER TO FIGS. 77-81.
                                   BN60Y

BORE      STROKE    NUMBER OF     CYCLE     BRAKE     AIR METER    FUEL     H/CARBON   CALORIFIC  TURBOCHARGED
                    CYLINDERS     TYPE     CONSTANT   CONSTANT     S.G.      RATIO      VALUE       OPTION
79.50      73.00        4          4.       9.0640    .000000     .8180      4.00     19940.00        0

DAY       MONTH       YEAR        TEST     BAROMETER   WET BULB    DRY BULB    POWER      FRICTION      OUTPUT
                                 NUMBER              TEMPERATURE TEMPERATURE CORRECTION   OPTION       OPTION
18          1          83        97.00      766.90     10.00       16.00        0           1.            4

   1 ENGINE SPEED (REV/S)                 50.00  50.00  50.00  40.00  40.00  40.00  40.00  40.00  60.00  60.00  60.00  60.00  80.00
 80.00  80.00
   2 BRAKE LOAD                            1.08   1.64   2.63    .98   1.64   2.63   3.60   4.60   1.64   2.63   3.60   4.60   2.63
  3.60   4.60
   3 FUEL MASS ( GRAMS )                 100.00 100.00 100.00 100.00 100.00 100.00 100.00 100.00 150.00 150.00 150.00 200.00 250.00
250.00 250.00
   5 FUEL TIME ( SEC )                    59.70  49.65  38.71  81.20  62.90  48.45  40.00  33.55  60.40  47.00  38.70  43.25  54.70
 45.10  38.70
   6 FUEL TEMPERATURE ( C )               15.00  15.00  15.00  15.00  15.00  15.00  15.00  16.00  15.00  14.00  14.00  13.00  13.00
 13.00  13.00
   8 AIR METER TEMPERATURE ( C )          42.00  39.00  43.00  41.00  34.00  36.00  39.00  44.00  37.00  37.00  39.00  38.00  37.00
 36.00  38.00
  12 HYDROCARBONS ( PPMC )              -1860.0-2010.0-1380.0-1710.0-1410.0-1650.0-1410.0 -990.0-1590.0-1140.0 -960.0-1140.0 -945.0
 -870.0 -840.0
  13 CARBON MONOXIDE ( % )                 .150   .140   .130   .140   .130   .130   .120   .090   .150   .130   .110   .100   .140
  .120   .100
  14 OXIDES OF NITROGEN ( PPM )          -290.0  -88.0 -370.0 -170.0 -420.0 -160.0 -260.0 -790.0 -240.0 -580.0 -920.0-1000.0 -950.0
1250.0-1400.0
  15 CARBON DIOXIDE ( % )                11.800 12.000 12.400 11.200 11.500 11.800 11.500 11.400 12.900 12.600 12.800 12.400 13.800
13.800 13.000
  16 OXYGEN ( % )                         4.400  4.200  3.500  5.000  4.700  4.200  4.800  5.200  3.300  3.200  3.000  3.600  1.800
 1.700  2.500
  28 IGNITION TIMING                      31.00  30.00  28.00  27.00  27.00  24.00  19.00  15.00  33.00  31.00  28.00  22.00  34.00
 30.00  24.00
  26 EXHAUST TEMPERATURE                  426.0  432.0  468.0  386.0  402.0  430.0  464.0  496.0  483.0  515.0  549.0  569.0  600.0
 621.0  638.0
  11 INTAKE MANIFOLD PRESS.(mm.Hg)-442.50-330.00-247.50-450.00-375.00-225.00-135.00 -60.00-345.00-262.50-183.75-105.00-285.00
206.25-112.50
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                    MAP
                                                                      REFER TO FIGS. 77-81.
                              AUTO FUEL IGN EGR

        DATE 18/ 1/83     TEST NO. 97.0    BAROMETER 766.90 MM.HG      WET BULB TEMP(C) 10.0
        RELATIVE HUMIDITY                 = 45.05                      DRY BULB TEMP(C) 16.0
        HUMIDITY CORRECTION FACTOR        =  1.35
        GRAINS OF WATER/LB DRY AIR        = 35.13

                      ::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                      ::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                         RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA
 SPEED   POWER      BMEP     TORQUE    FUEL     VOLUMETRIC          AIR FUEL      B.T.E.    H C      NOX      C O       CO2     HC + NOX
 REV/S    KW        BAR       N.M    G/KW.HR   EFFICIENCY(%)         RATIO          %     G/KW.HR  G/KW.HR  G/KW.HR   G/KW.HR   G/KW.HR
 50.0     5.96      1.64     18.96   1012.2     32.3(     .0)      7.9(    .0)    17.84     9.60     6.00    10.90   1347.37     15.60
 50.0     9.05      2.50     28.80    801.5     38.0(     .0)      7.8(    .0)    22.53     8.10     1.34     7.92   1066.65      9.44
 50.0    14.51      4.00     46.18    641.0     47.8(     .0)      7.6(    .0)    28.16     4.36     4.99     5.74    859.84      9.36
 40.0     4.32      1.49     17.21   1025.1     30.8(     .0)      8.2(    .0)    17.61     9.33     3.54    10.87   1365.97     12.87
 40.0     7.24      2.50     28.80    790.8     38.2(     .0)      8.1(    .0)    22.83     5.83     5.80     7.62   1058.67     11.64
 40.0    11.61      4.00     46.18    640.2     48.5(     .0)      7.9(    .0)    28.20     5.40     1.85     6.00    855.45      7.25
 40.0    15.89      5.48     63.21    566.5     61.4(     .0)      8.1(    .0)    31.87     4.18     2.84     5.04    759.03      7.02
 40.0    20.30      7.00     80.77    528.6     76.3(     .0)      8.3(    .0)    34.16     2.78     8.92     3.58    713.07     11.70
 60.0    10.86      2.50     28.80    823.5     37.0(     .0)      7.4(    .0)    21.92     6.24     3.49     8.15   1101.68      9.74
 60.0    17.41      4.00     46.18    659.9     47.7(     .0)      7.5(    .0)    27.36     3.67     6.92     5.83    887.59     10.59
 60.0    23.83      5.48     63.21    585.5     57.8(     .0)      7.4(    .0)    30.83     2.72    10.19     4.32    790.32     12.91
 60.0    30.45      7.00     80.77    546.7     70.8(     .0)      7.6(    .0)    33.02     3.09    10.13     3.78    736.82     13.22
 80.0    23.21      4.00     46.18    708.8     47.7(     .0)      7.0(    .0)    25.47     3.05    11.85     6.17    955.90     14.91
 80.0    31.77      5.48     63.21    628.0     57.6(     .0)      6.9(    .0)    28.75     2.49    13.49     4.70    848.78     15.99
 80.0    40.60      7.00     80.77    572.8     70.4(     .0)      7.2(    .0)    31.52     2.30    14.85     3.79    774.80     17.16
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  MAP

             AUTO FUEL IGN EGR

                            BN60Y
                                                                       REFER TO FIGS. 77-81.

 BORE        STROKE      NUMBER OF       CYCLE       BRAKE      AIR METER      FUEL      H/CARBON    CALORIFIC    TURBOCHARGED
                         CYLINDERS        TYPE      CONSTANT     CONSTANT      S.G.       RATIO        VALUE         OPTION
79.50         73.00          4             4.        9.0640      .000000      .8180       4.00       19940.00          0

 DAY         MONTH          YEAR         TEST      BAROMETER     WET BULB     DRY BULB     POWER       FRICTION        OUTPUT
                                        NUMBER                 TEMPERATURE  TEMPERATURE  CORRECTION     OPTION         OPTION
 18            1             83          98.00       767.70       12.00        21.00         0            1.              4


   1 ENGINE SPEED (REV/S)                  50.00  50.00  70.00  70.00  70.00  70.00  20.00  20.00  20.00  20.00  20.00  30.00  30.00
 30.00  30.00  30.00
   2 BRAKE LOAD                             3.60   4.60   1.64   2.63   3.60   4.60    .98   1.64   2.63   3.60   4.00    .98   1.64
  2.63   3.60   4.30
   3 FUEL MASS ( GRAMS )                  150.00 150.00 150.00 150.00 150.00 150.00  50.00  50.00  50.00  50.00  50.00  50.00  50.00
 50.00  50.00  70.00
   5 FUEL TIME ( SEC )                     47.40  59.70  49.40  39.00  32.20  27.00  82.00  63.85  47.80  39.60  36.50  54.00  41.80
 33.30  26.70  32.30
   6 FUEL TEMPERATURE ( C )                17.00  17.00  16.00  16.00  15.00  15.00  16.00  16.00  17.00  17.00  17.00  17.00  16.00
 16.00  16.00  16.00
   8 AIR METER TEMPERATURE ( C )           44.00  46.00  38.00  38.00  38.00  37.00  36.00  36.00  36.00  37.00  38.00  39.00  34.00
 36.00  40.00  47.00
  12 HYDROCARBONS ( PPMC )               -1200.0 -990.0-1320.0-1080.0 -990.0-1050.0-1620.0-1800.0-1350.0-1320.0-1290.0-1560.0-1320.0
1320.0-1230.0-1320.0
  13 CARBON MONOXIDE ( % )                  .110   .100   .150   .140   .120   .100   .140   .130   .130   .110   .100   .140   .130
  .120   .110   .100
  14 OXIDES OF NITROGEN ( PPM )           -380.0 -900.0 -380.0 -770.0-1100.0-1200.0 -120.0 -250.0 -900.0 -380.0 -800.0 -210.0 -480.0
-370.0 -210.0 -740.0
  15 CARBON DIOXIDE ( % )                 11.200 11.800 12.400 12.600 12.600 12.300 11.400 11.000 12.000 10.300 10.700 11.700 11.800
11.500 11.300 10.700
  16 OXYGEN ( % )                          5.000  4.100  3.300  2.800  2.800  3.200  5.000  5.300  3.800  6.200  5.800  4.400  4.300
 4.800  5.000  5.700
  28 IGNITION TIMING                       23.00  19.00  35.00  33.00  29.00  24.00  22.00  23.00  19.00  11.00   9.00  23.00  23.00
 21.00  14.00  12.00
  26 EXHAUST TEMPERATURE                   498.0  537.0  511.0  550.0  581.0  603.0  264.0  281.0  309.0  362.0  388.0  353.0  356.0
 382.0  427.0  453.0
  11 INTAKE MANIFOLD PRESS.(mm.Hg)-135.00 -82.50-345.00-270.00-187.50-105.00-412.50-337.50-247.50 -97.50 -52.50-442.50-375.00
255.00-112.50 -60.00
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              MAP                                                               REFER TO FIGS. 77-81.

                        AUTO FUEL IGN EGR

     DATE 18/ 1/83     TEST NO. 98.0    BAROMETER 767.70 MM.HG     WET BULB TEMP(C) 12.0
                                                                   DRY BULB TEMP(C) 21.0
     RELATIVE HUMIDITY            = 31.71
     HUMIDITY CORRECTION FACTOR   =  1.46
     GRAINS OF WATER/LB DRY AIR   = 33.77

                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                    : IF POWER = 0.0 RESULTS LISTED AS G/KW-HR ARE ACTUALLY G/HR :
                    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                      RESULTS IN (BRACKETS) ARE CALCULATED FROM AIR METER DATA

SPEED   POWER     BMEP    TORQUE    FUEL    VOLUMETRIC        AIR FUEL     B.T.E.    H C      NOX      C O      CO2      HC + NOX
REV/S    KW        BAR     N.M    G/KW.HR  EFFICIENCY(%)        RATIO         %     G/KW.HR  G/KW.HR  G/KW.HR  G/KW.HR   G/KW.HR

50.0    19.86     5.48    63.21    573.7     64.2(    .0)     8.3(    .0)   31.47     3.69     4.75     4.82   770.58     8.44
50.0    25.38     7.00    80.77    356.5     48.9(    .0)     7.9(    .0)   50.65     1.82     7.39     2.59   480.74     9.21
70.0    12.67     2.50    28.80    863.1     39.1(    .0)     7.5(    .0)   20.92     5.62     6.14     8.90  1156.54    11.75
70.0    20.31     4.00    46.18    681.7     48.5(    .0)     7.3(    .0)   26.48     3.60     9.87     6.48   916.68    13.46
70.0    27.80     5.48    63.21    603.2     58.8(    .0)     7.3(    .0)   29.93     2.92    12.49     4.93   813.09    15.41
70.0    35.53     7.00    80.77    563.0     71.5(    .0)     7.5(    .0)   32.07     2.95    12.48     3.93   759.32    15.43
20.0     2.16     1.49    17.21   1015.1     29.9(    .0)     8.2(    .0)   17.79     8.64     2.21    10.59  1354.56    10.85
20.0     3.62     2.50    28.80    779.0     39.1(    .0)     8.4(    .0)   23.18     7.57     3.60     7.80  1037.45    11.17
20.0     5.80     4.00    46.18    648.9     48.2(    .0)     7.7(    .0)   27.82     4.44    10.54     6.00   870.06    14.97
20.0     7.94     5.48    63.21    572.2     67.4(    .0)     8.9(    .0)   31.55     4.33     4.22     5.21   766.24     8.55
20.0     8.83     6.09    70.24    558.7     71.4(    .0)     8.7(    .0)   32.31     4.01     8.69     4.46   749.76    12.69
30.0     3.24     1.49    17.21   1027.7     29.6(    .0)     7.9(    .0)   17.57     8.26     4.16    10.46  1373.03    12.42
30.0     5.43     2.50    28.80    793.3     37.5(    .0)     7.9(    .0)   22.76     5.37     6.60     7.46  1063.65    11.98
30.0     8.70     4.00    46.18    621.0     48.7(    .0)     8.1(    .0)   29.07     4.30     4.18     5.53   832.80     8.48
30.0    11.92     5.48    63.21    565.8     62.3(    .0)     8.2(    .0)   31.91     3.71     2.36     4.71   759.89     6.07
30.0    14.23     6.55    75.51    548.2     77.1(    .0)     8.6(    .0)   32.93     4.02     9.43     4.37   735.35    13.46
```
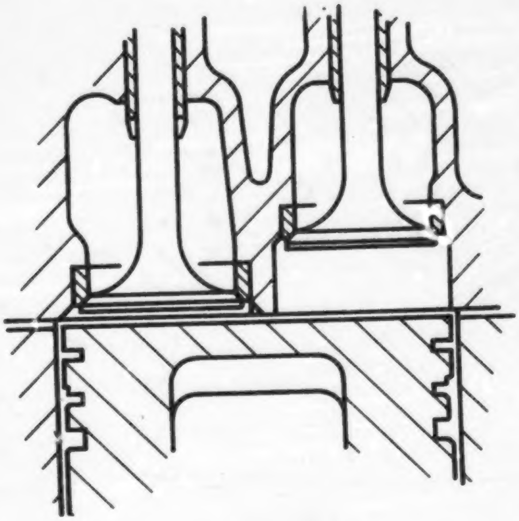

C.R.M. /L.M.

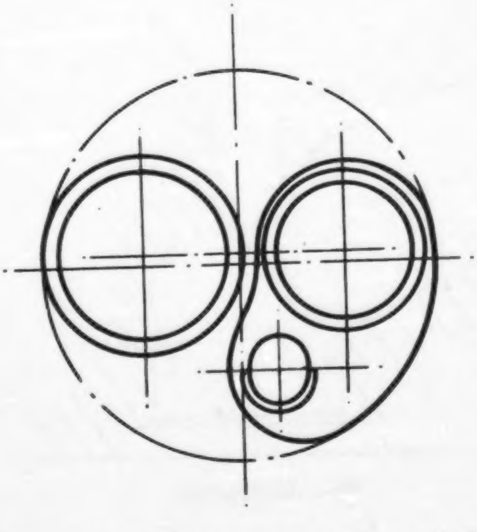
RICARDO

FIG. No. 1
Drg. No. S. 9803
Date MARCH '83

RICARDO MULTI-CYLINDER HRCC



Transverse Section



View on Cylinder Head Face

C.D.B./L.M.

RICARDO

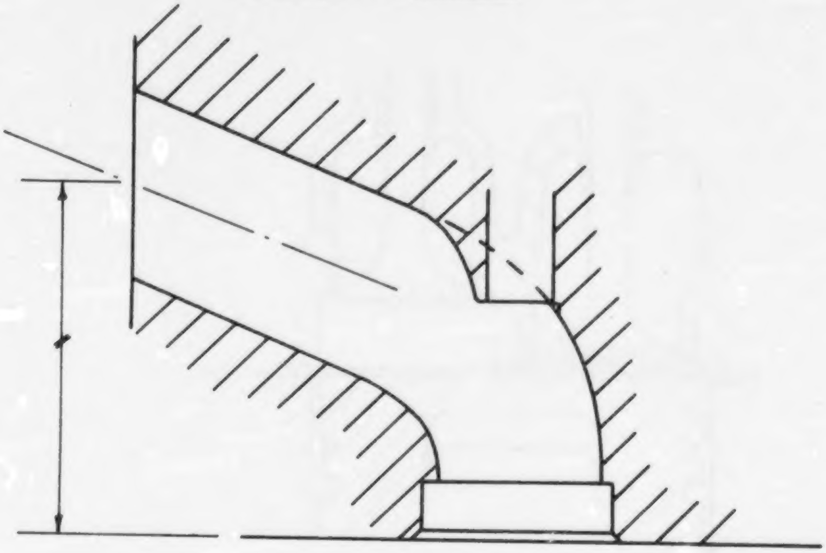
FIG. No. 2

Drg. No. S. 7223

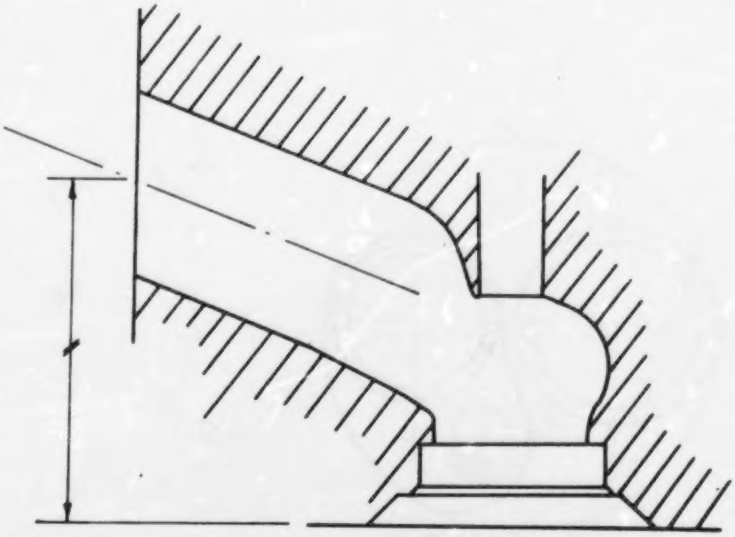
Date MAY '82

RICARDO MULTICYLINDER HRCC

INLET PORT DESIGN



HRCC



1·6L. BASELINE

[illegible]

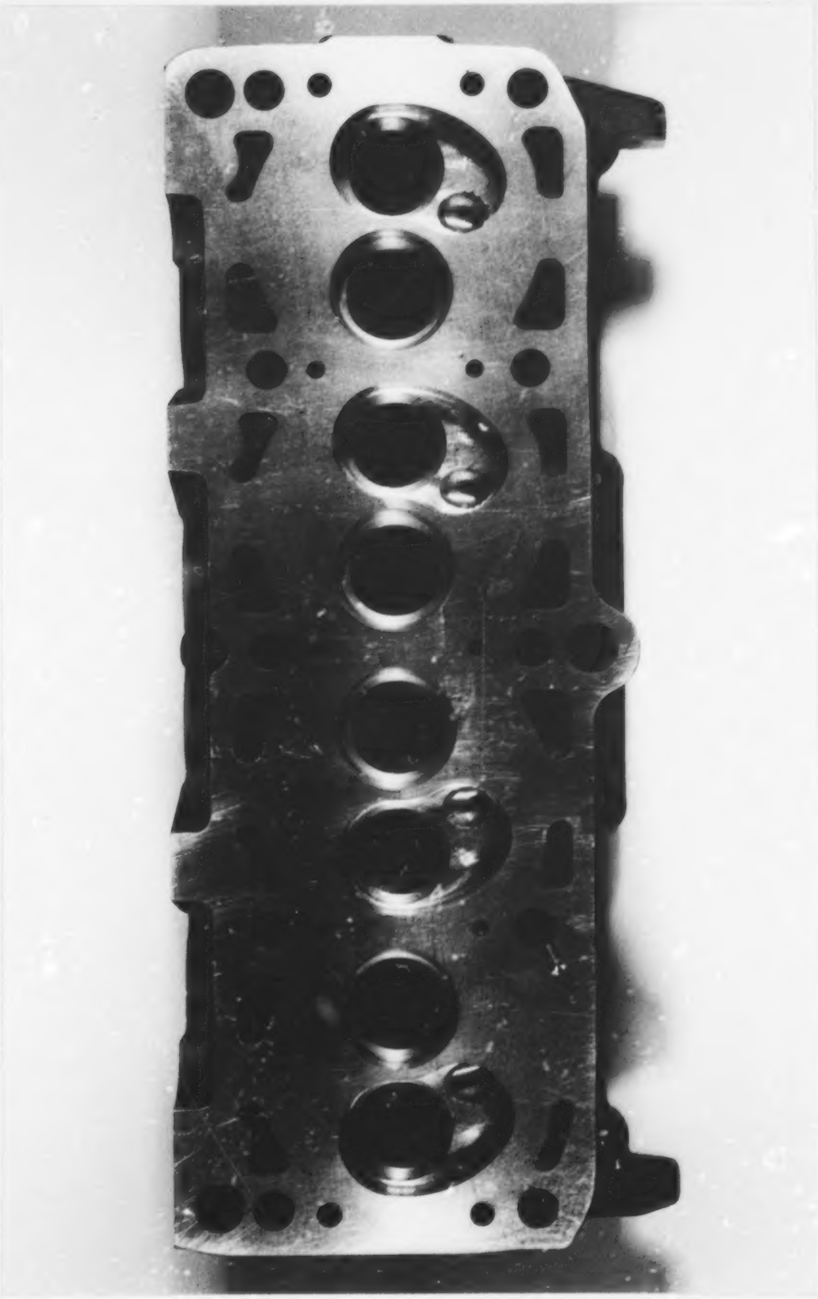
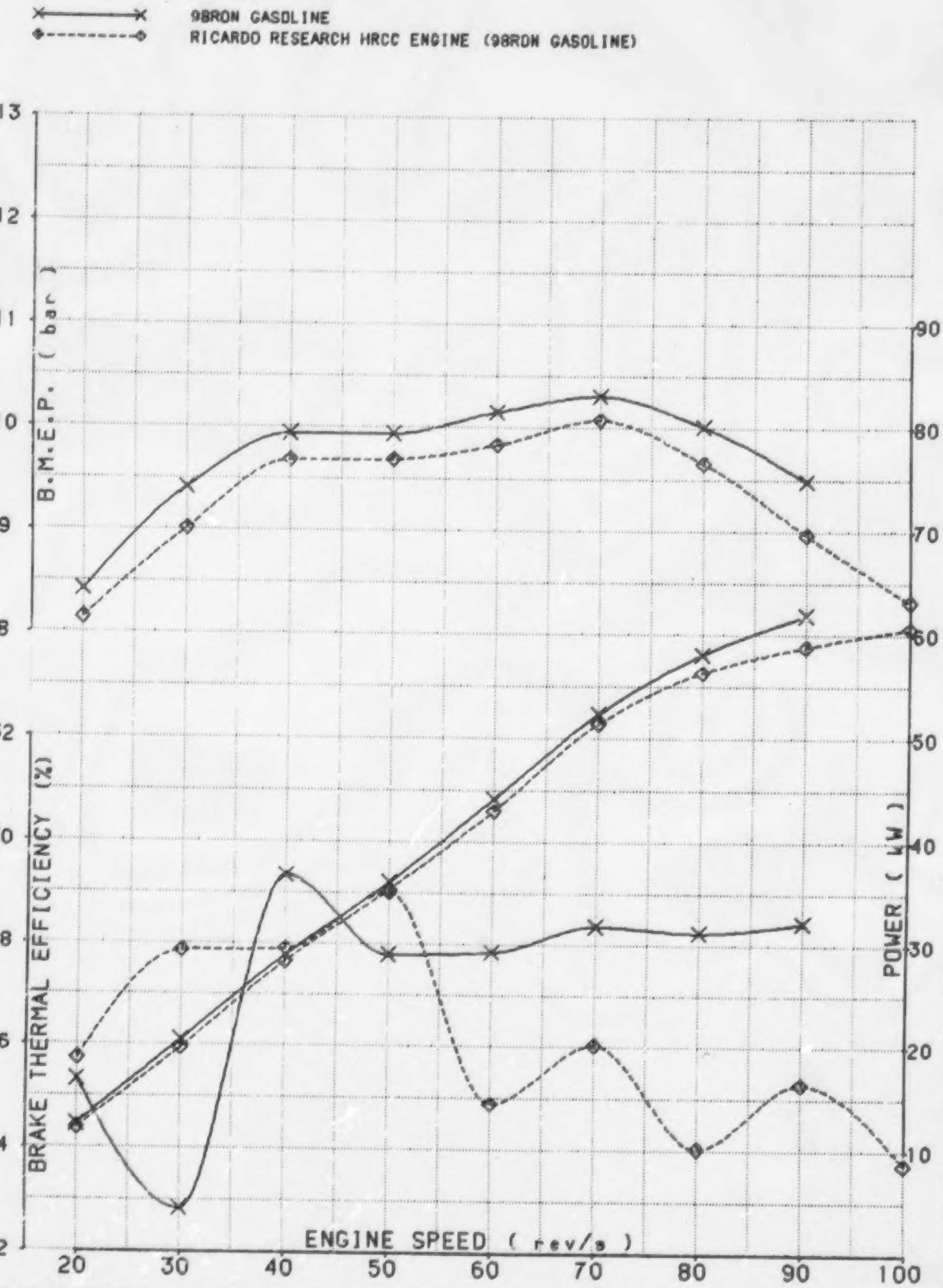


FIG. 3 HRCC CYLINDER HEAD

RICARDO

Fig.No. 4
Drg.No.
Date: 28 Jan 1983

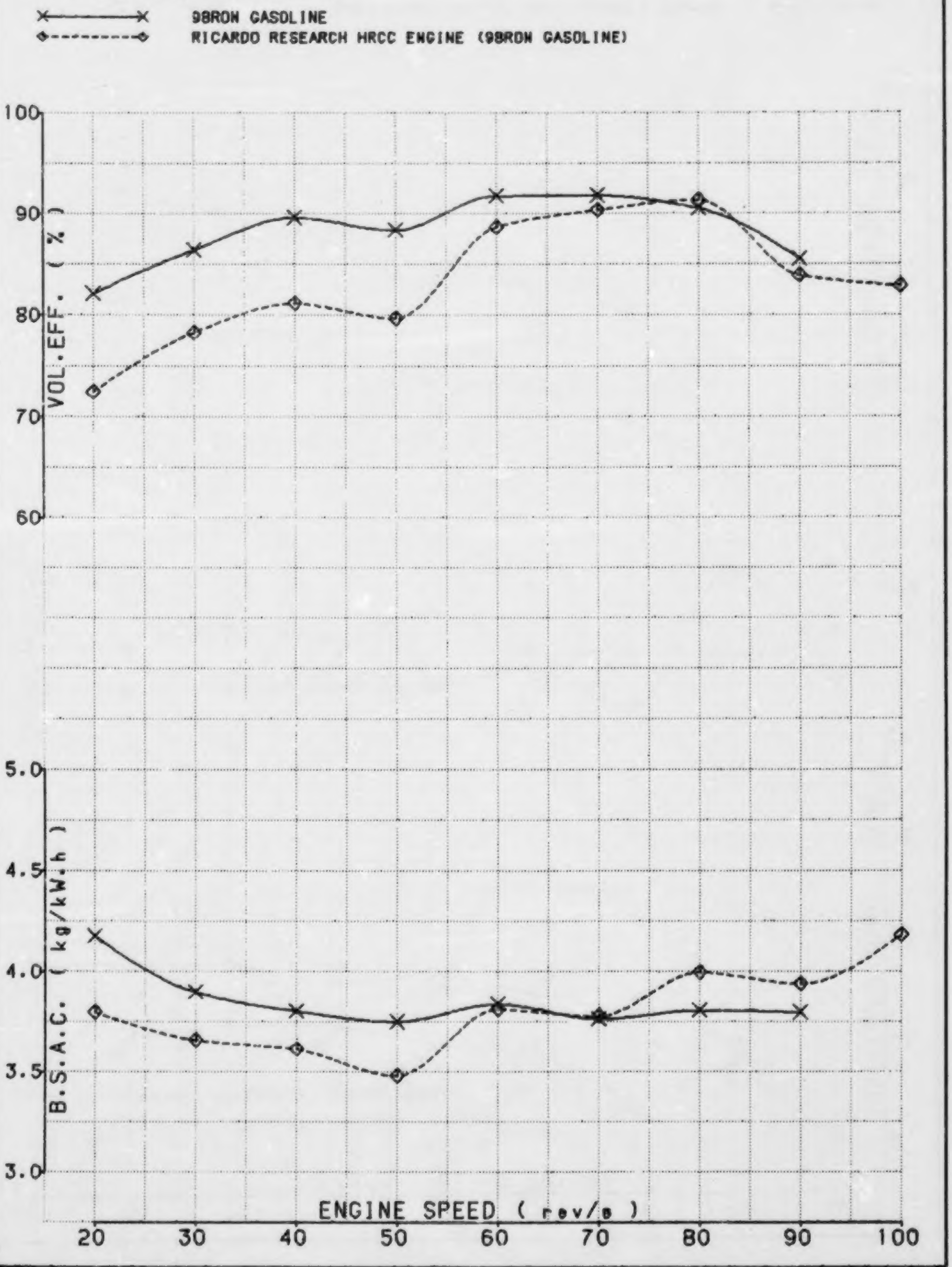
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
FULL LOAD POWER CURVE



RICARDO

Fig.No. 5
Drg.No.
Date: 28 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
FULL LOAD POWER CURVE



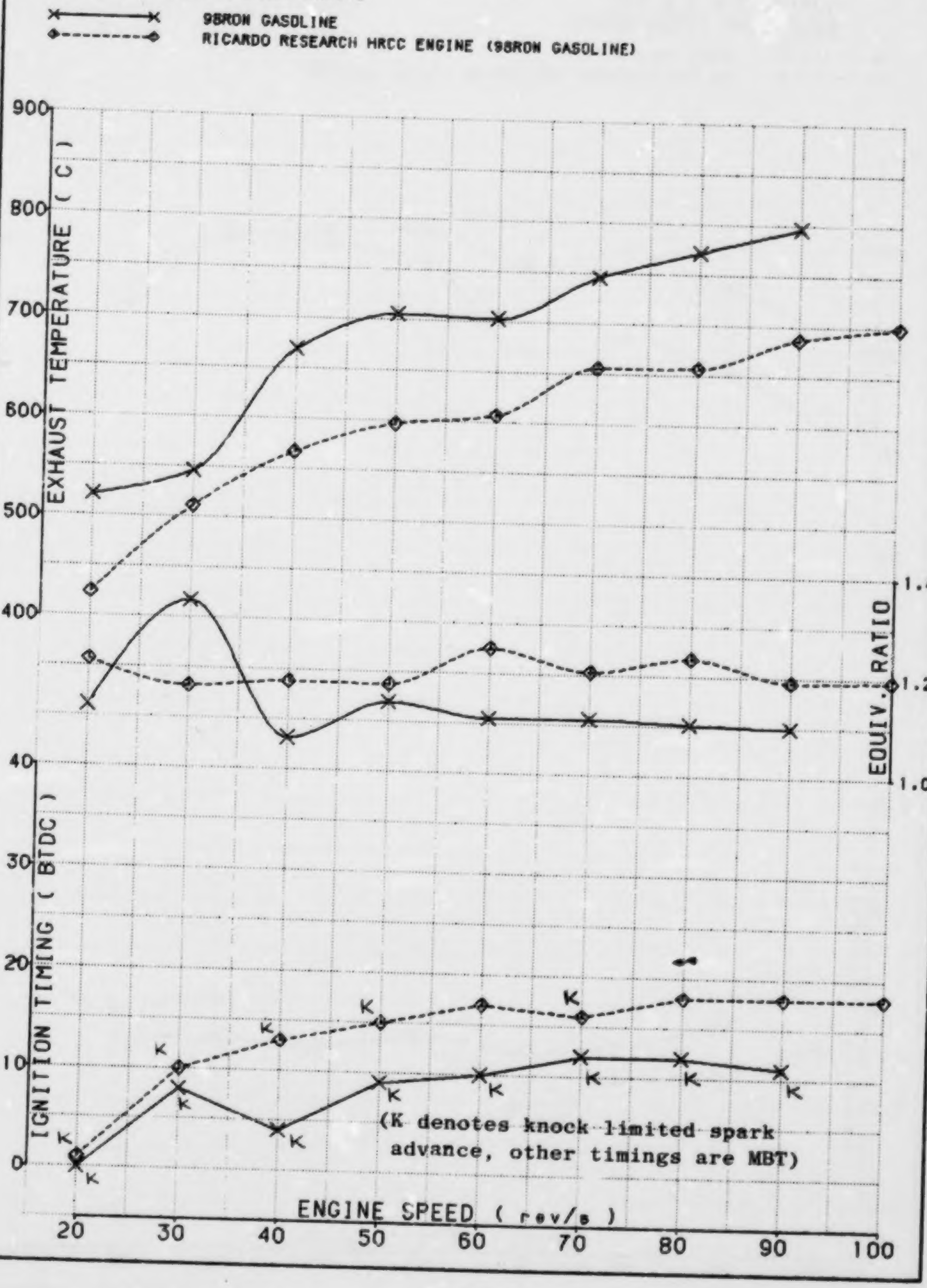
RICARDO

Fig.No. 6

Drg.No.

Date: 28 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
FULL LOAD POWER CURVE



(K denotes knock limited spark advance, other timings are MBT)

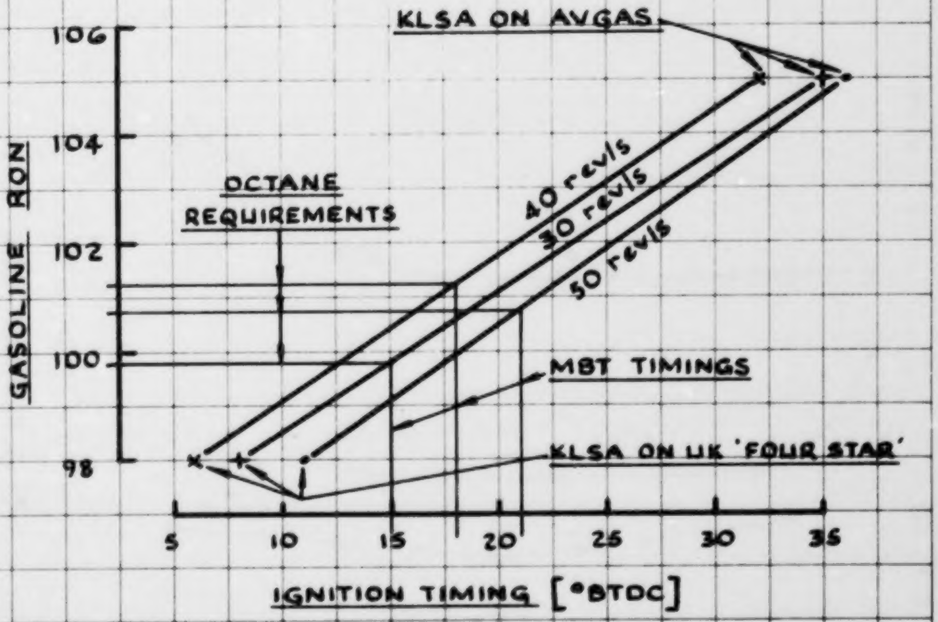
/M.B.

RICARDO

FIG. No. 7
Drg. No. D 50040
Date Feb '83

EPA 1·5ℓ HRCC ENGINE

OCTANE REQUIREMENT TESTS
'AUTOMATIC' CARBURETTER FUELLING.

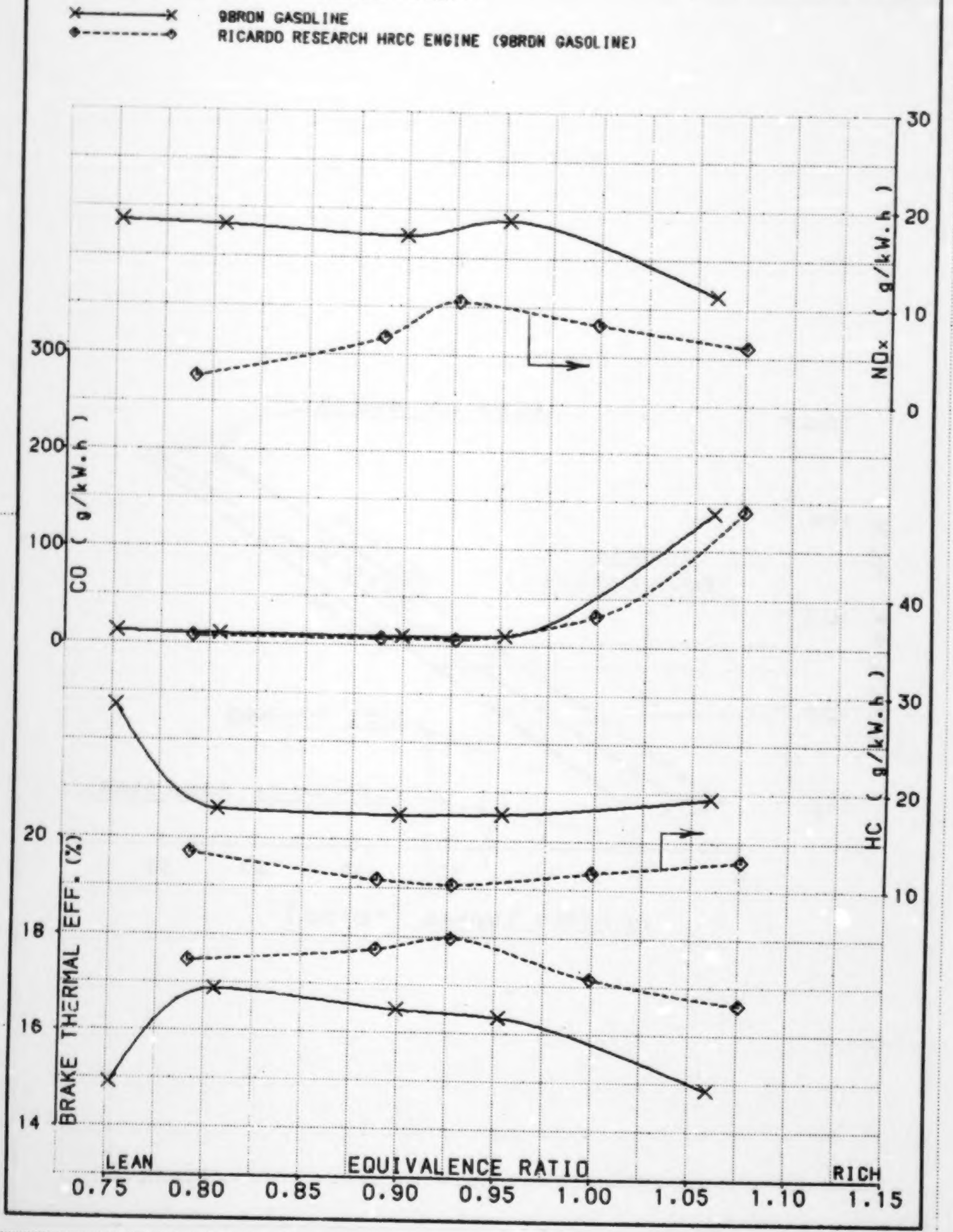


W M LTD 2317

RICARDO

Fig.No. 8
Drg.No.
Date: 28 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP • 20REV/S 1.5BAR



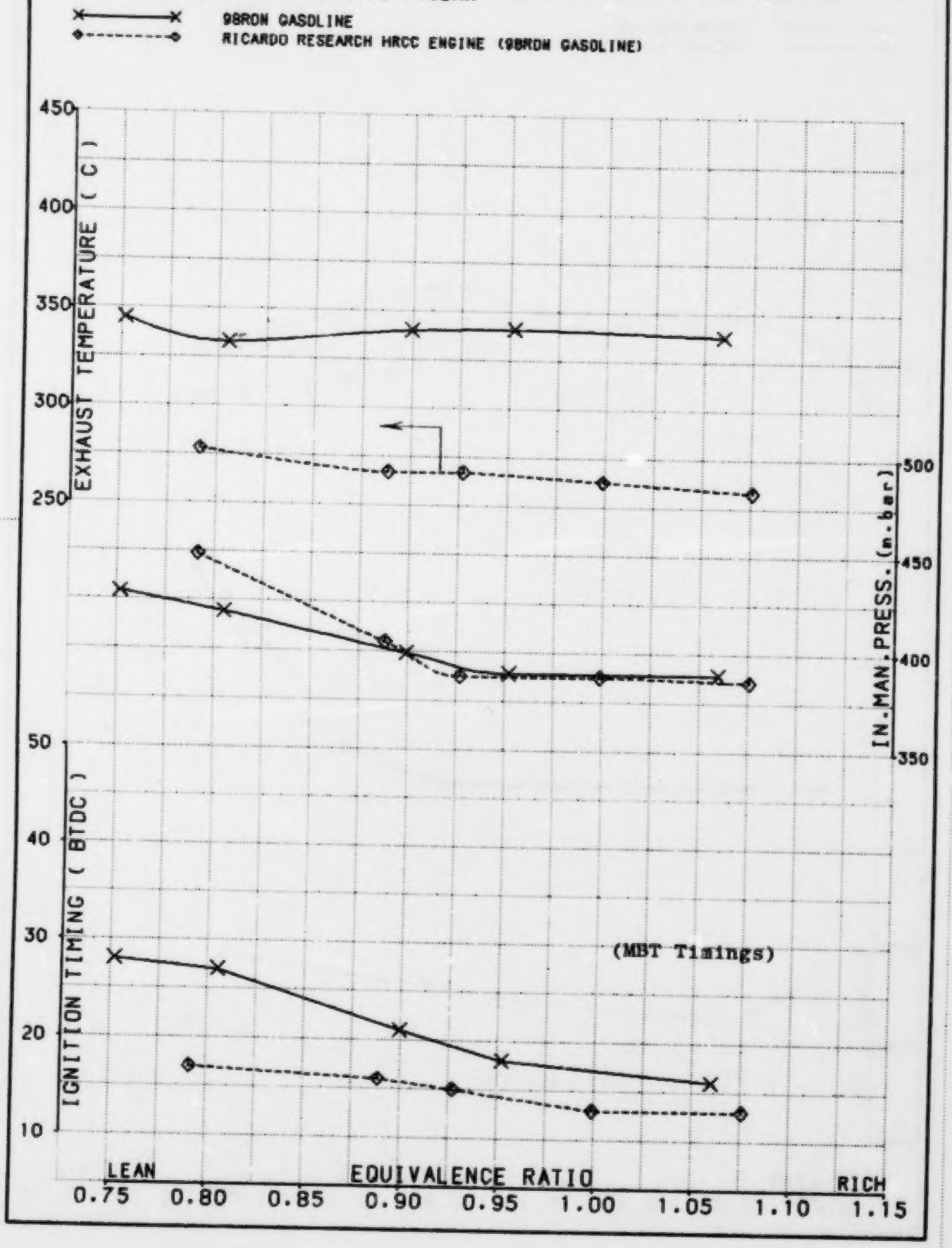
RICARDO

Fig.No. 9

Drg.No.

Date: 28 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 20REV/S 1.5BAR



RICARDO

Fig.No. 10
Drg.No.
Date: 28 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP • 20REV/S 1.5BAR

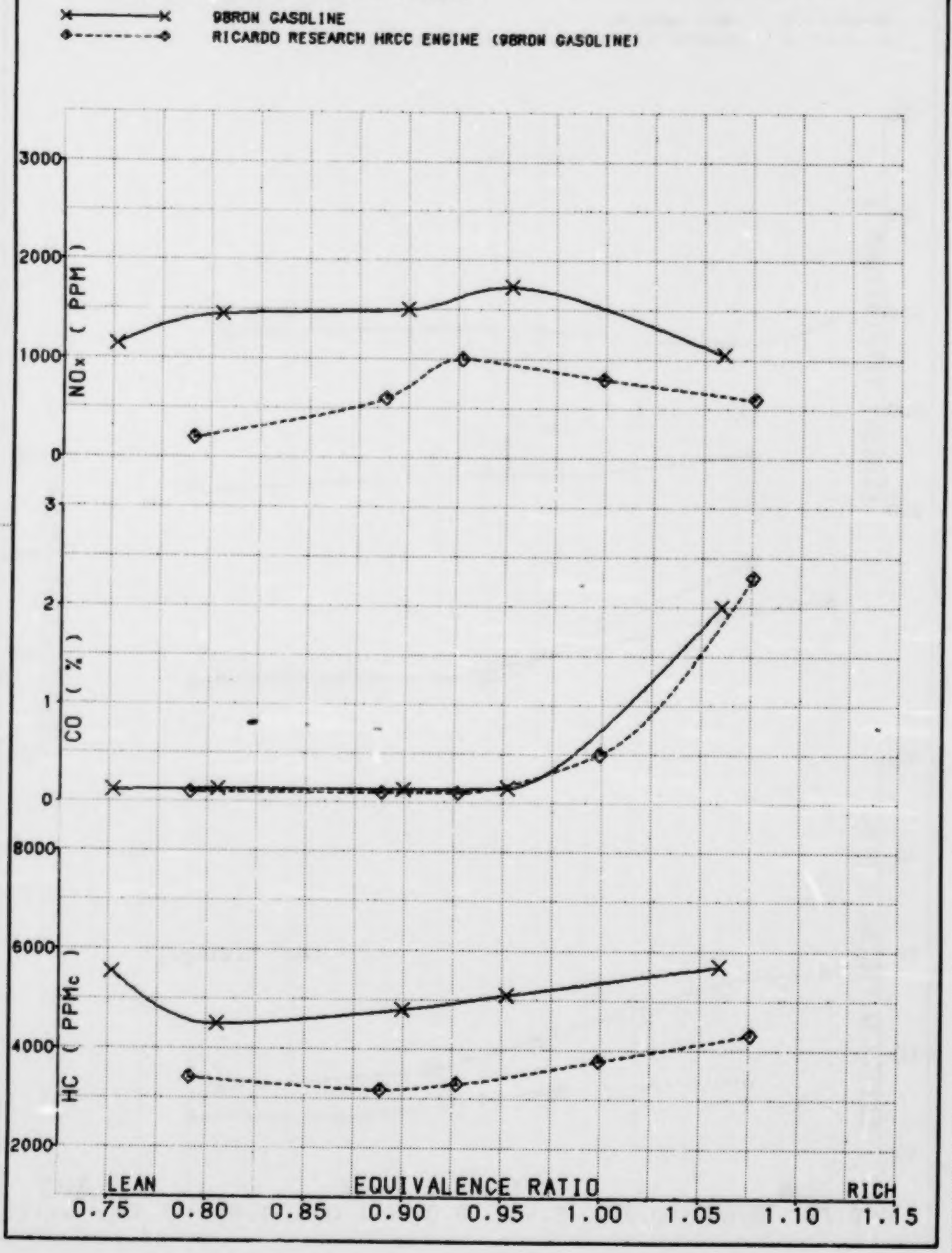


Fig.No. 11

Drg.No.

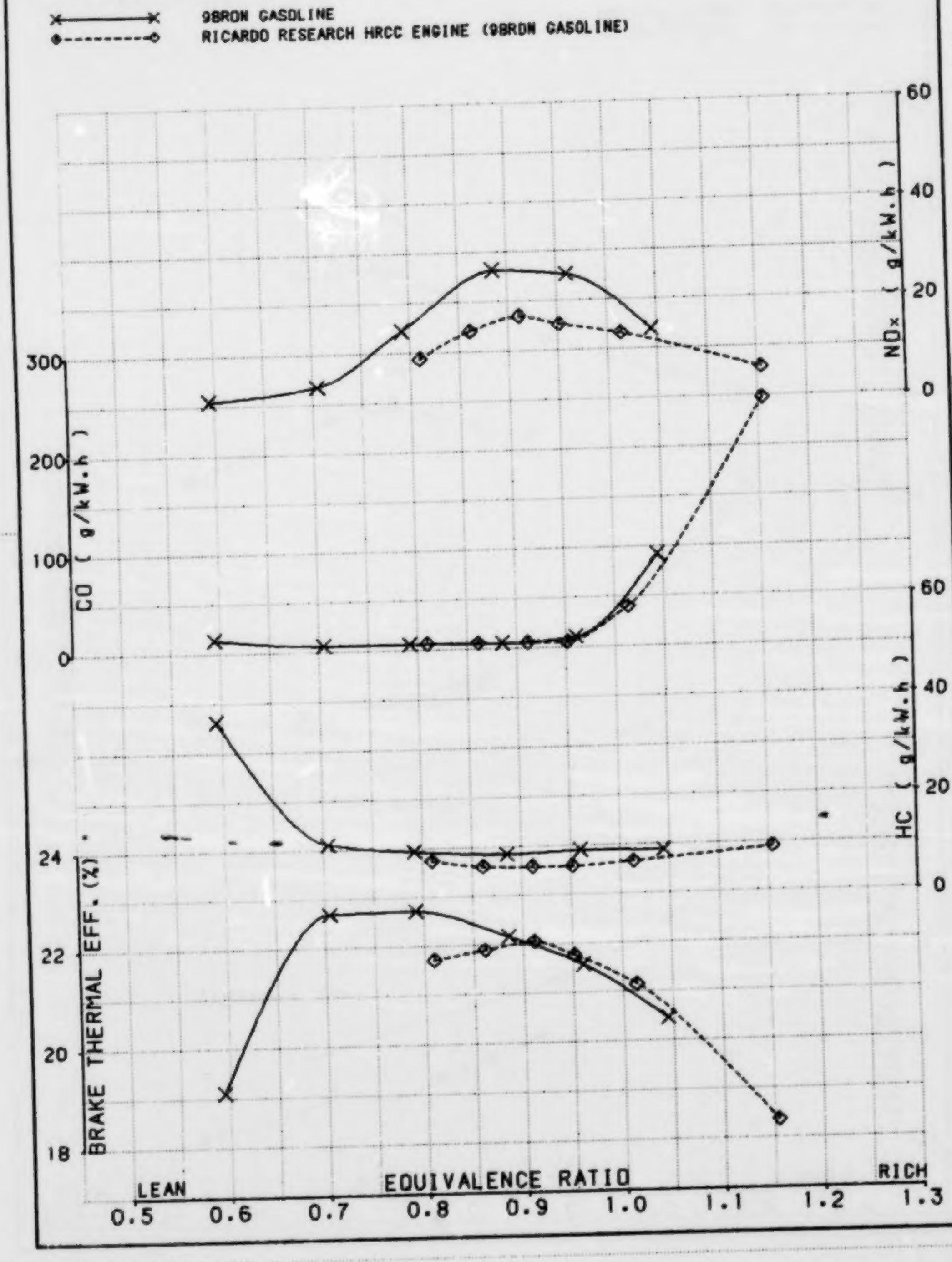
Date: 28 Jan 1983

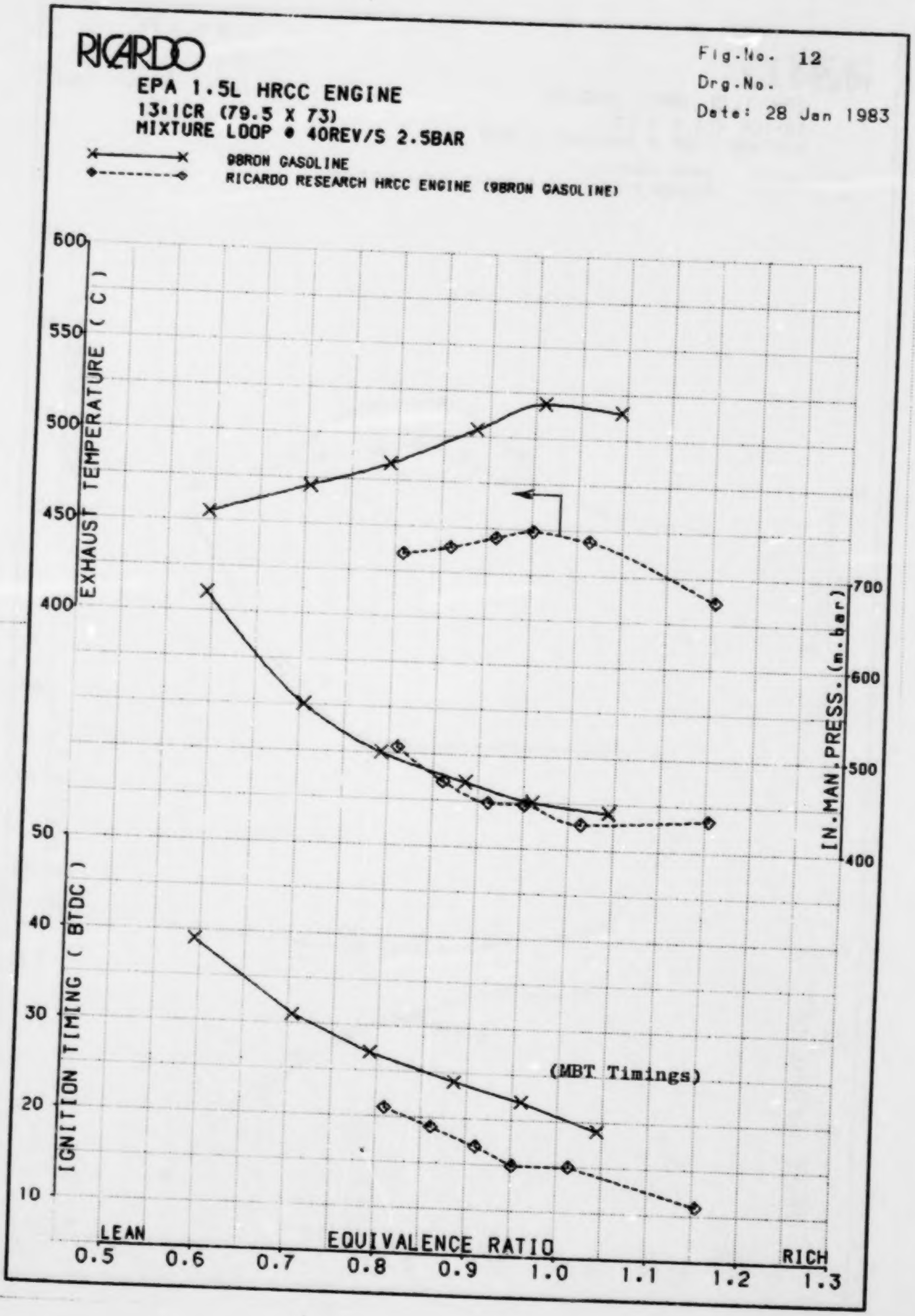
RICARDO

EPA 1.5L HRCC ENGINE

13:1CR (79.5 X 73)

MIXTURE LOOP • 40REV/S 2.5BAR





RICARDO

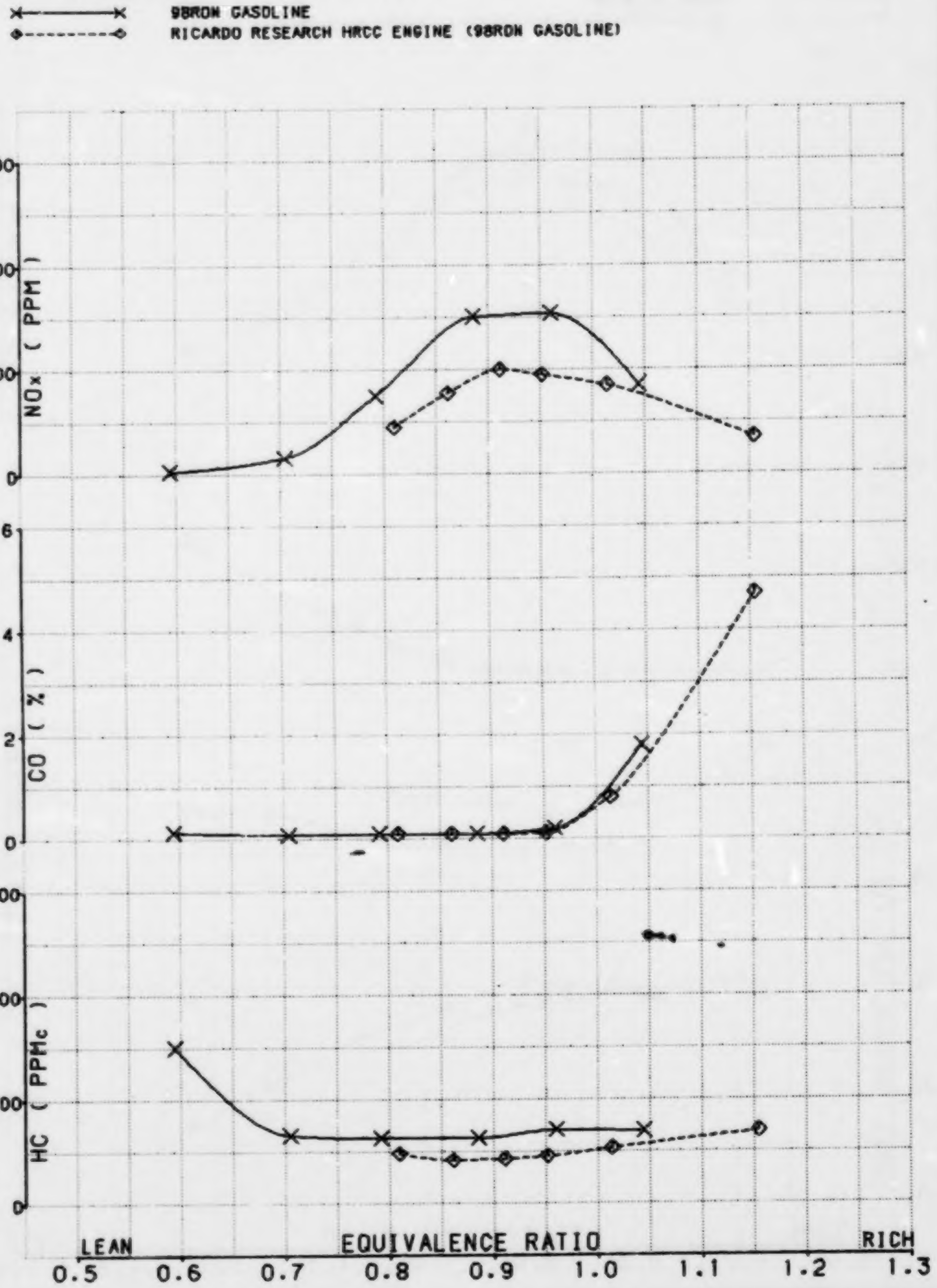
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 40REV/S 2.5BAR

Fig.No. 12
Drg.No.
Date: 28 Jan 1983

Fig. No. 13
Drg. No.
Date: 28 Jan 1983

RICARDO

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 40REV/S 2.5BAR



RICARDO

Fig.No. 14
Drg.No.
Date: 28 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 40REV/S 5.5BAR

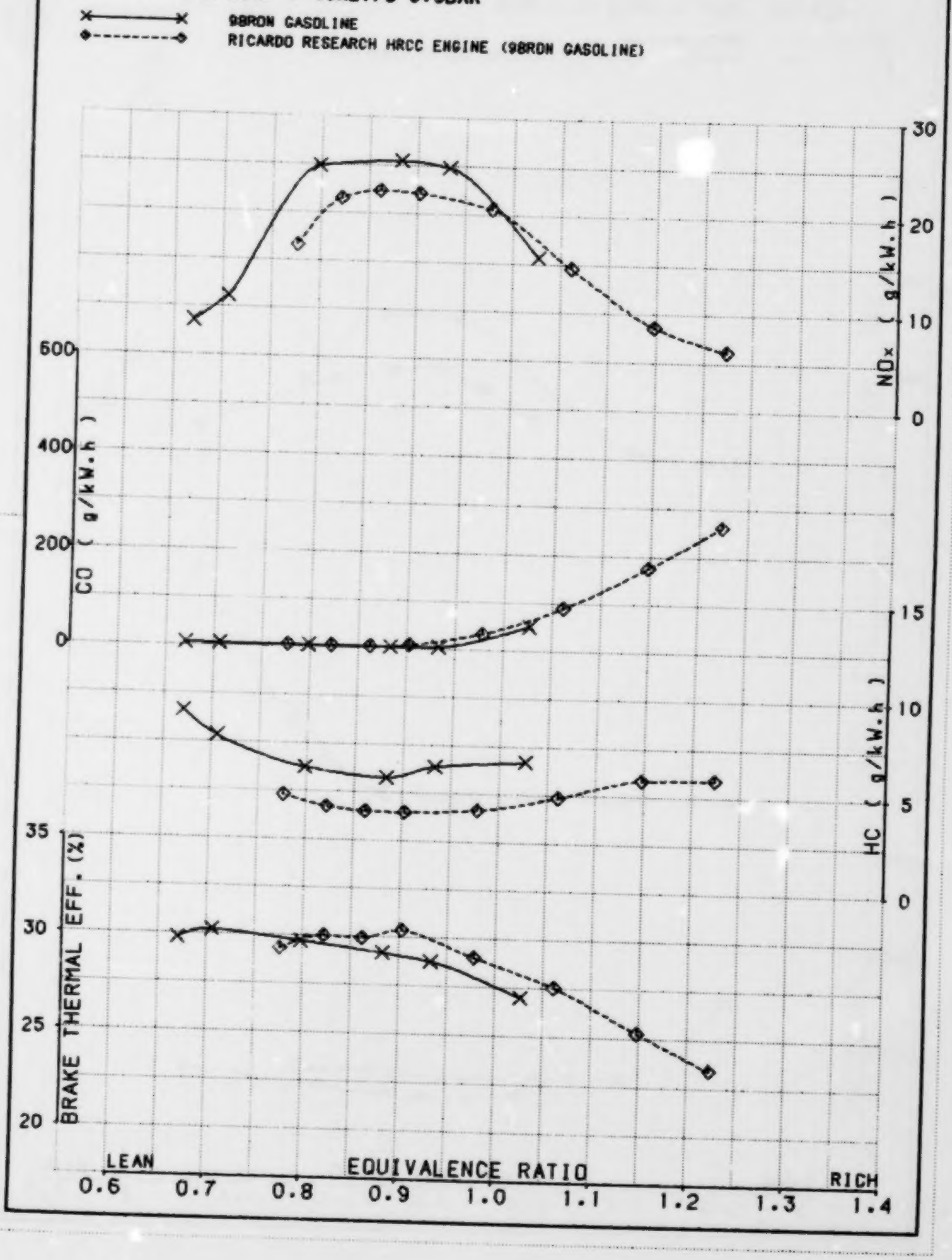
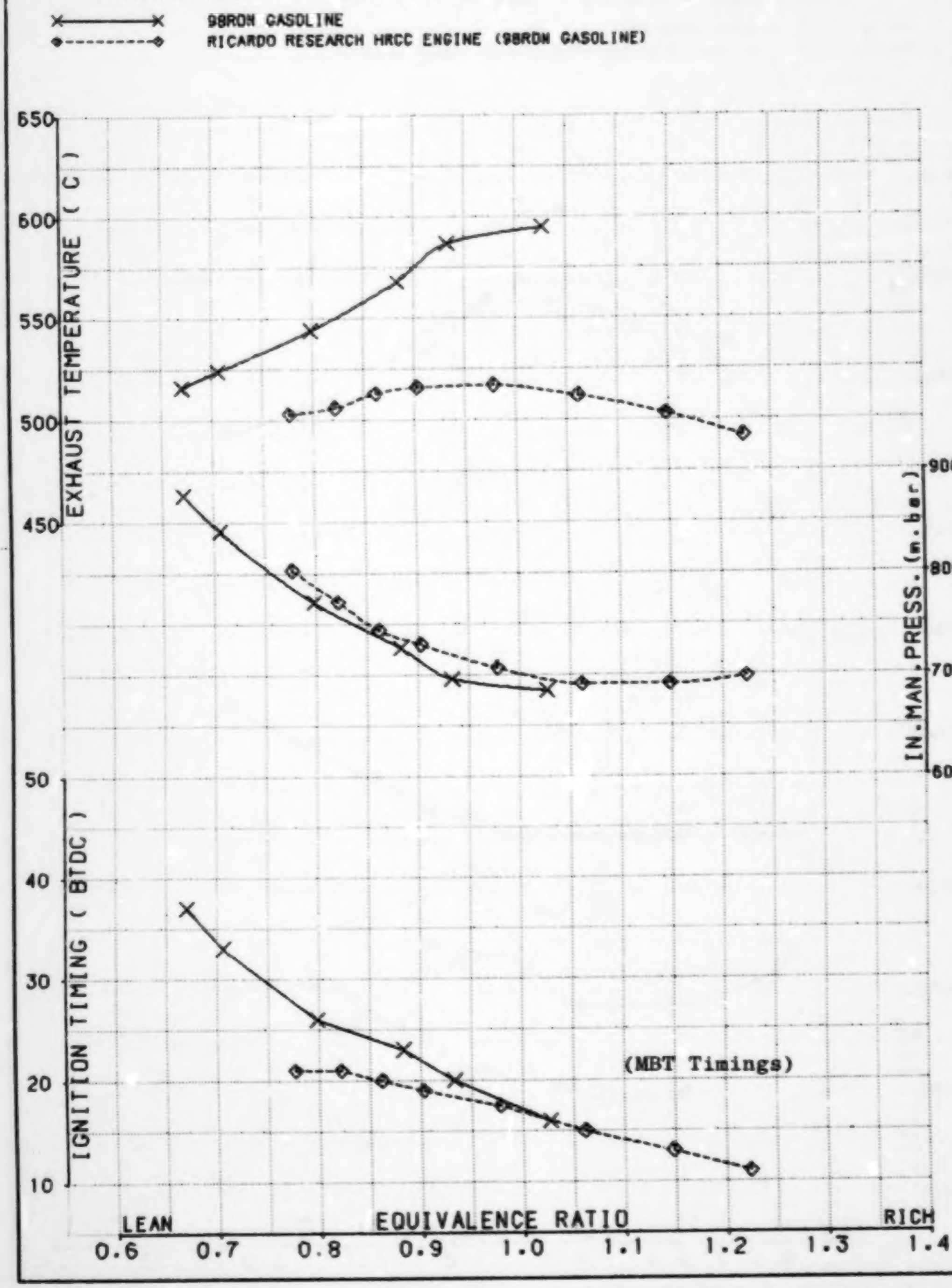


Fig.No. 15
Drg.No.
Date: 28 Jan 1983

RICARDO

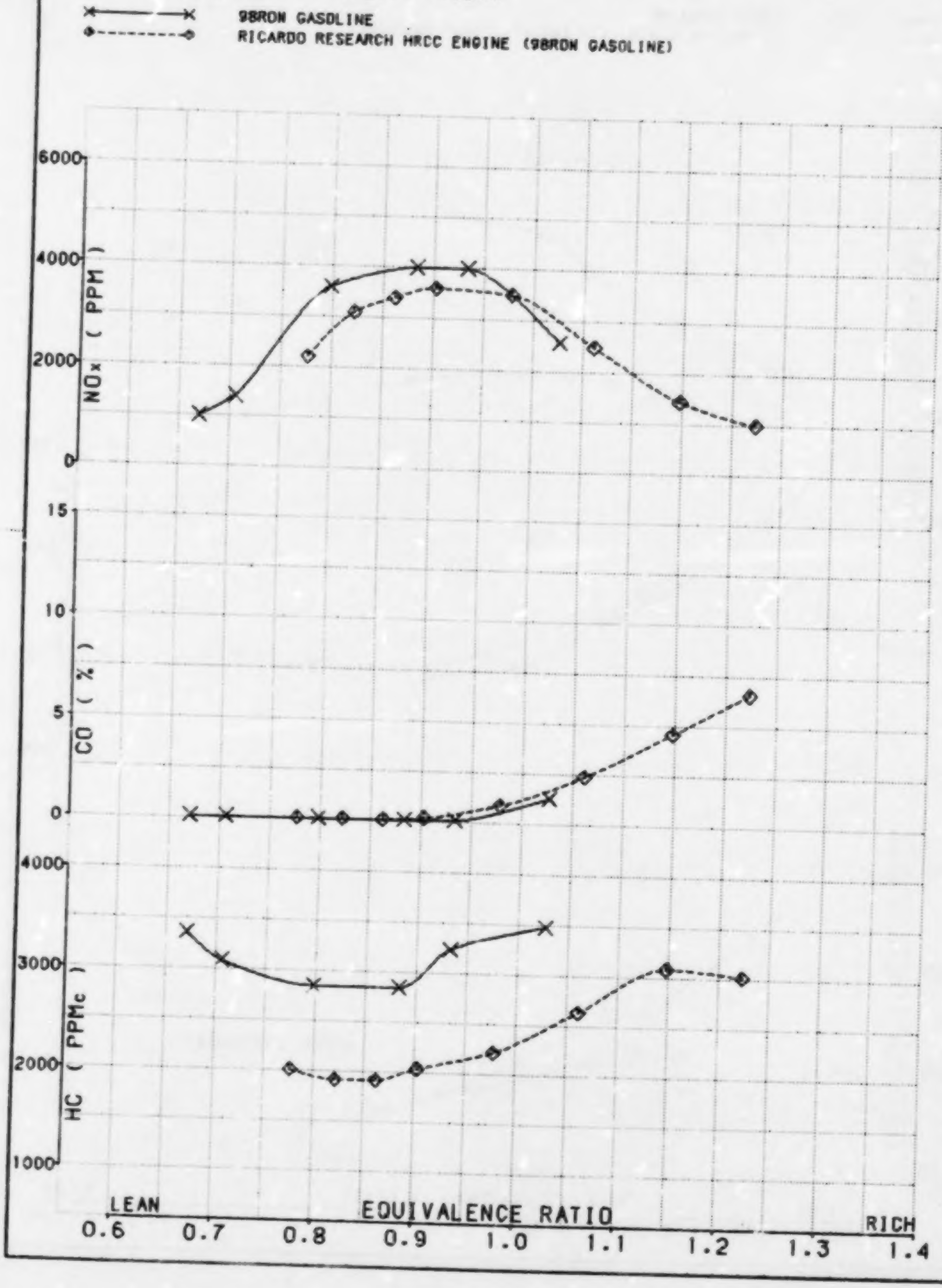
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 40REV/S 5.5BAR



RICARDO

Fig.No. 16
Drg.No.
Date: 28 Jan 1983

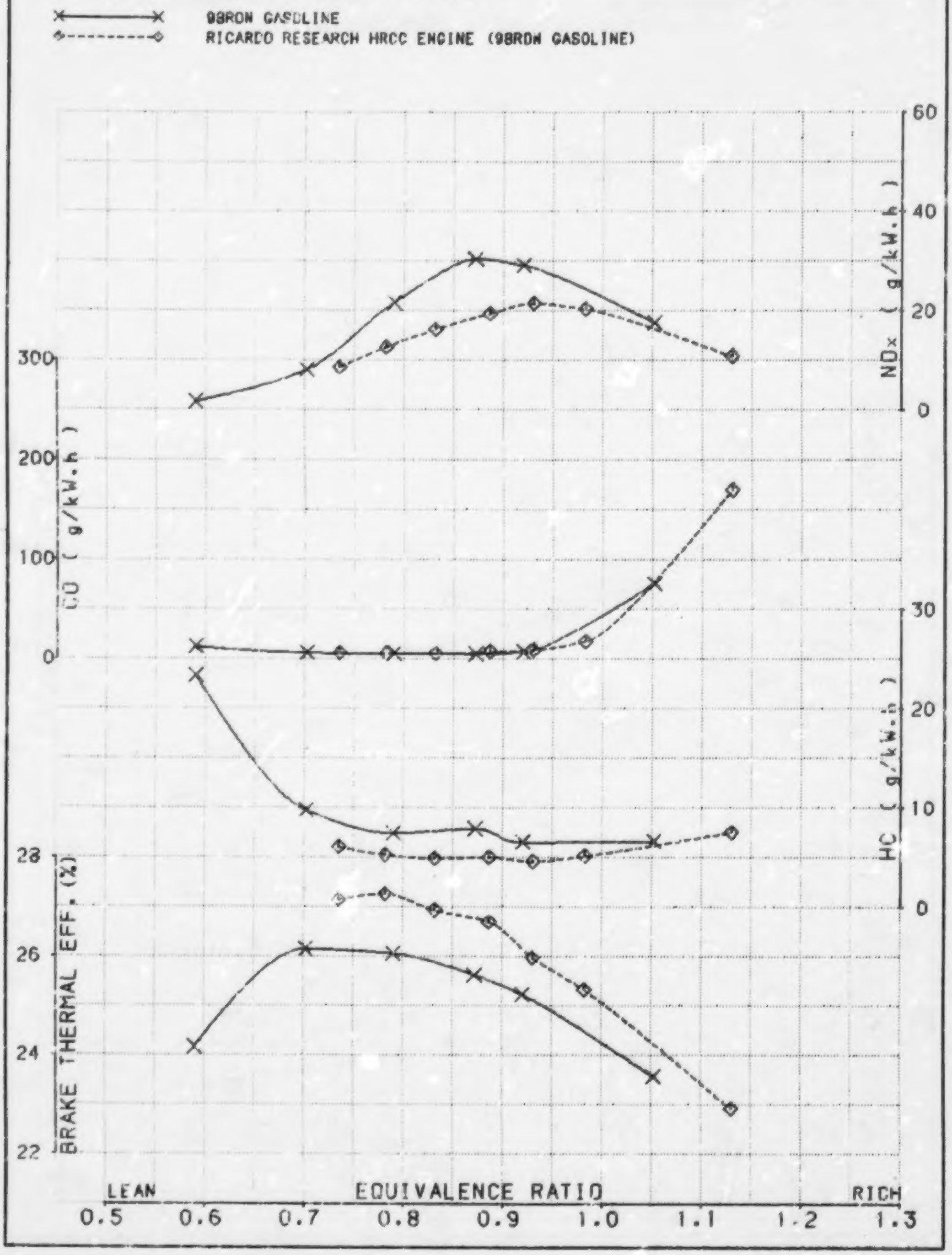
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 40REV/S 5.5BAR

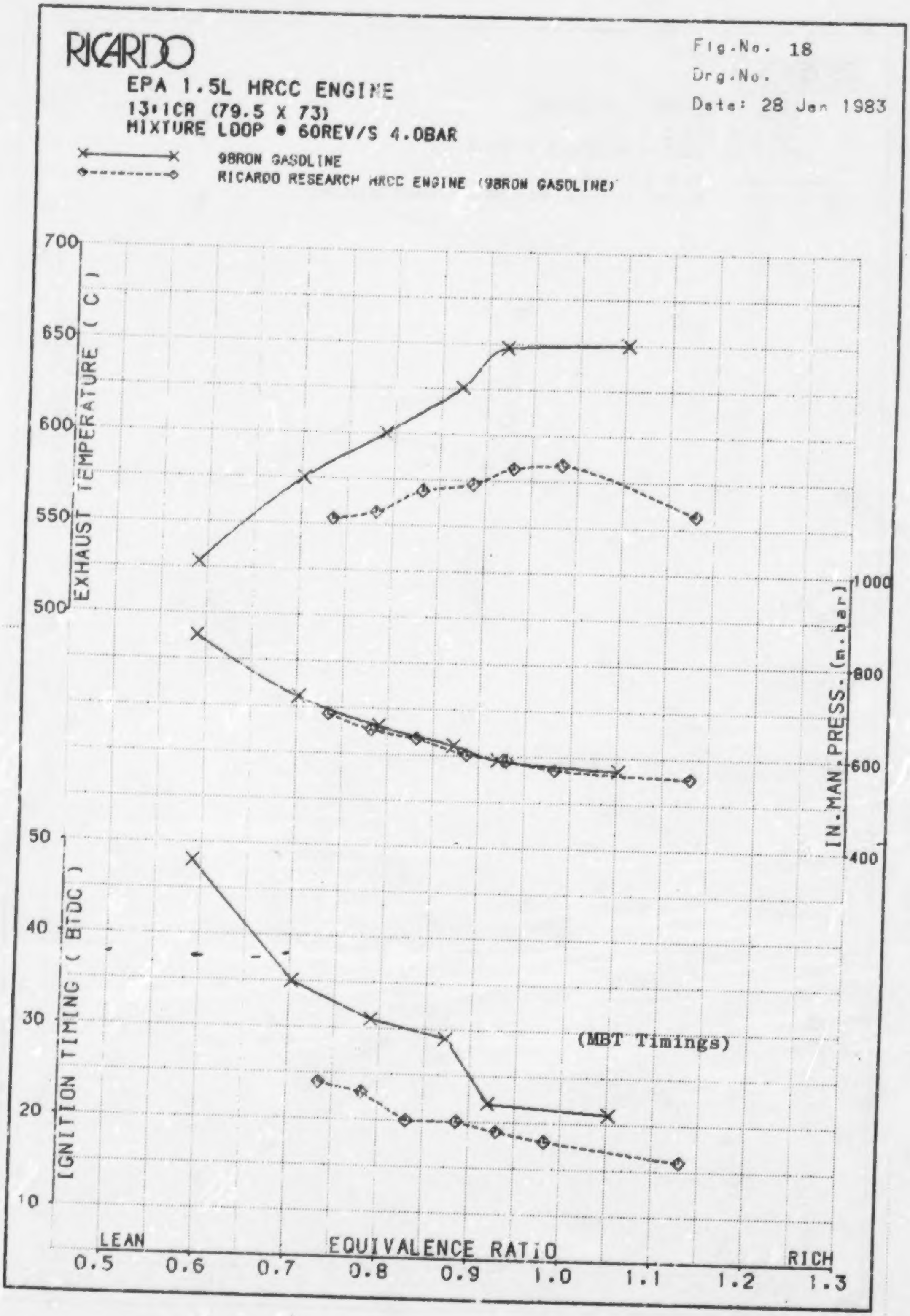


RICARDO

Fig. No. 17
Drg. No.
Date: 28 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 60REV/S 4.0BAR

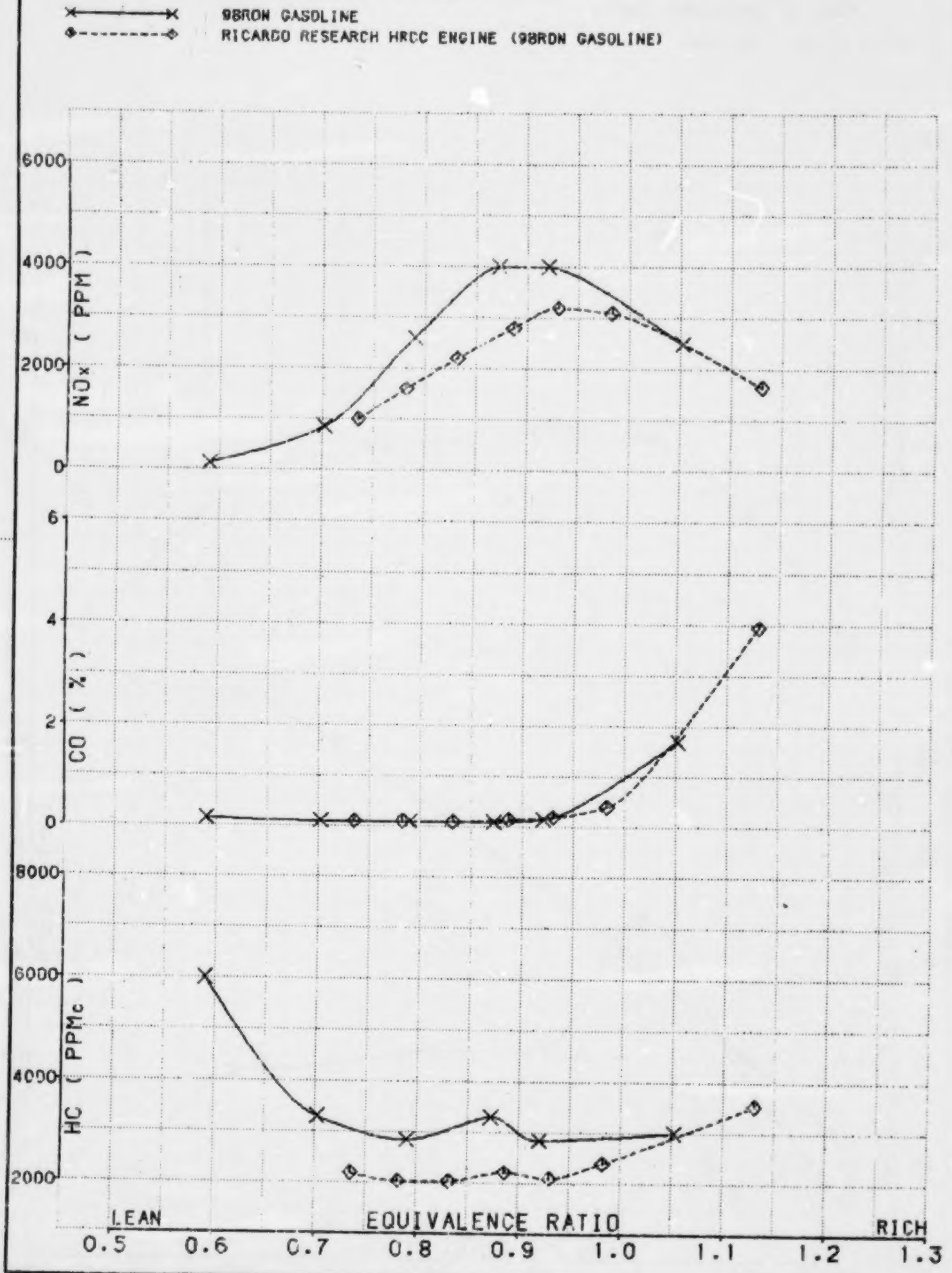



RICARDO
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP • 60REV/S 4.0BAR
Fig.No. 18
Drg.No.
Date: 28 Jan 1983
98RON GASOLINE
RICARDO RESEARCH HRCC ENGINE (98RON GASOLINE)
EXHAUST TEMPERATURE (C)
700
650
600
550
500
IN.MAN.PRESS.(m.bar)
1000
800
600
400
IGNITION TIMING (BTDC)
50
40
30
20
10
(MBT Timings)
LEAN
EQUIVALENCE RATIO
RICH
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3

RICARDO

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 60REV/S 4.0BAR

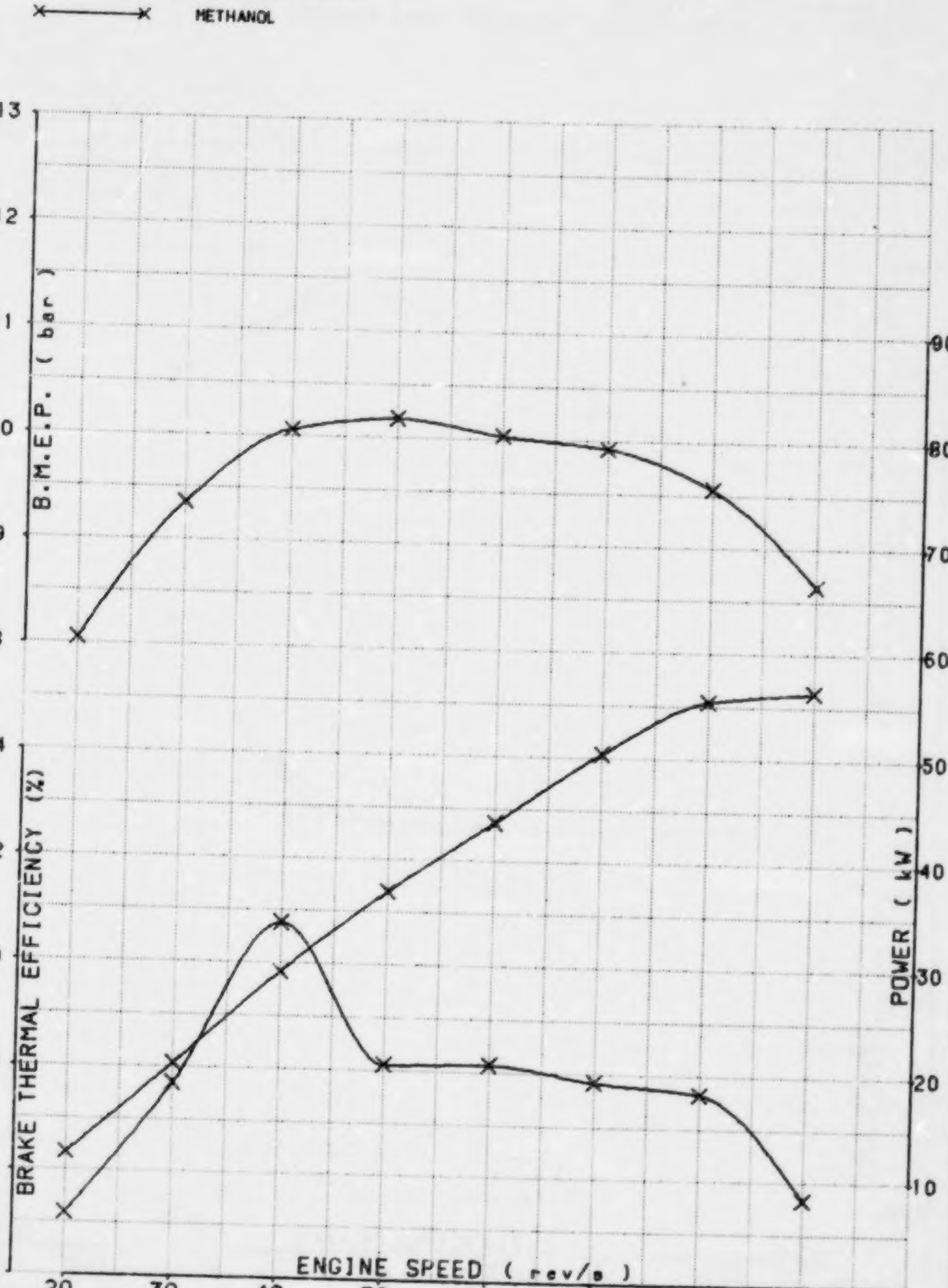
Fig.No. 19
Drg.No.
Date: 28 Jan 1983



RICARDO

Fig.No. 20
Drg.No.
Date: 16 Aug 1982

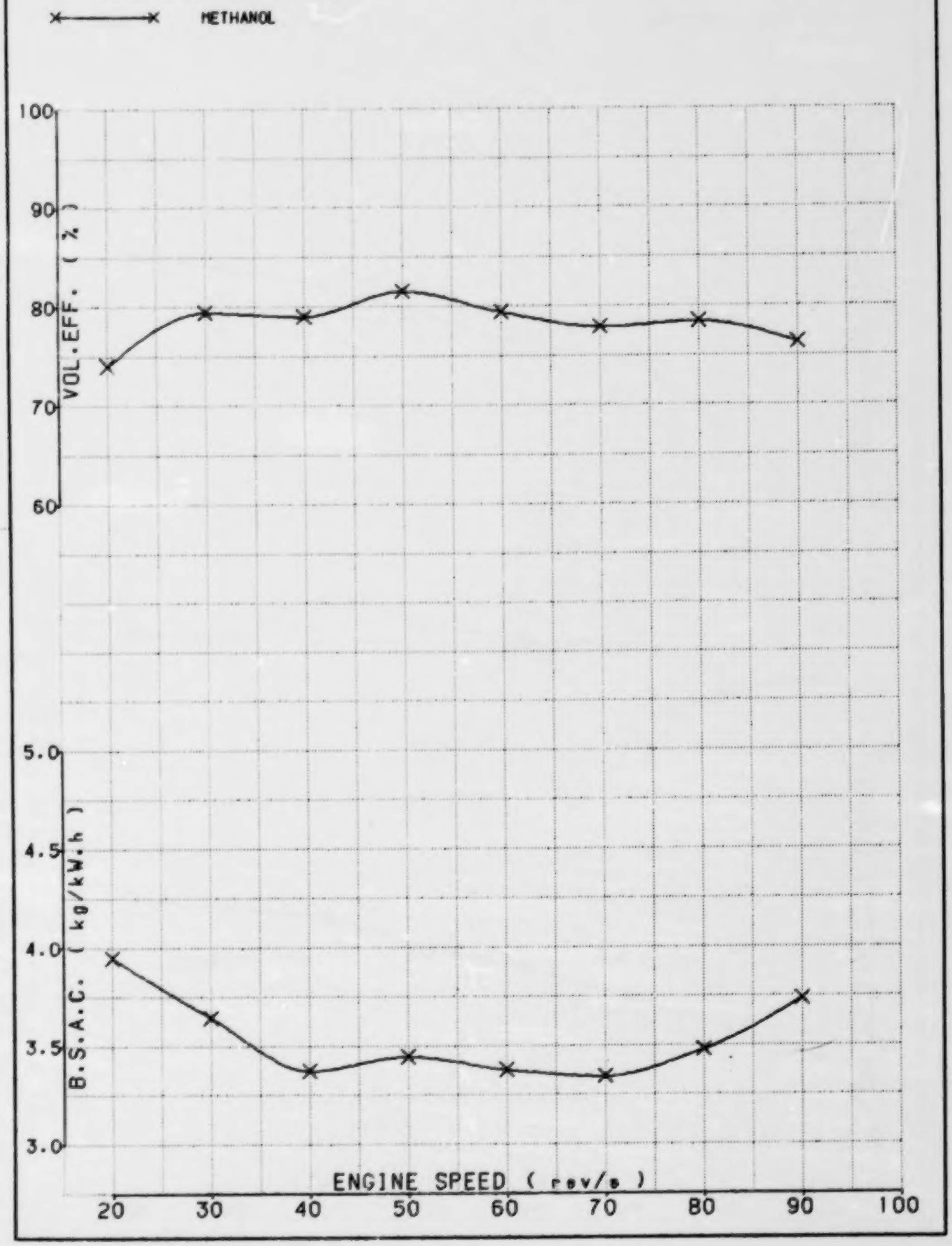
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
FULL LOAD POWER CURVE



RICARDO

Fig.No. 21
Drg.No.
Date: 16 Aug 1982

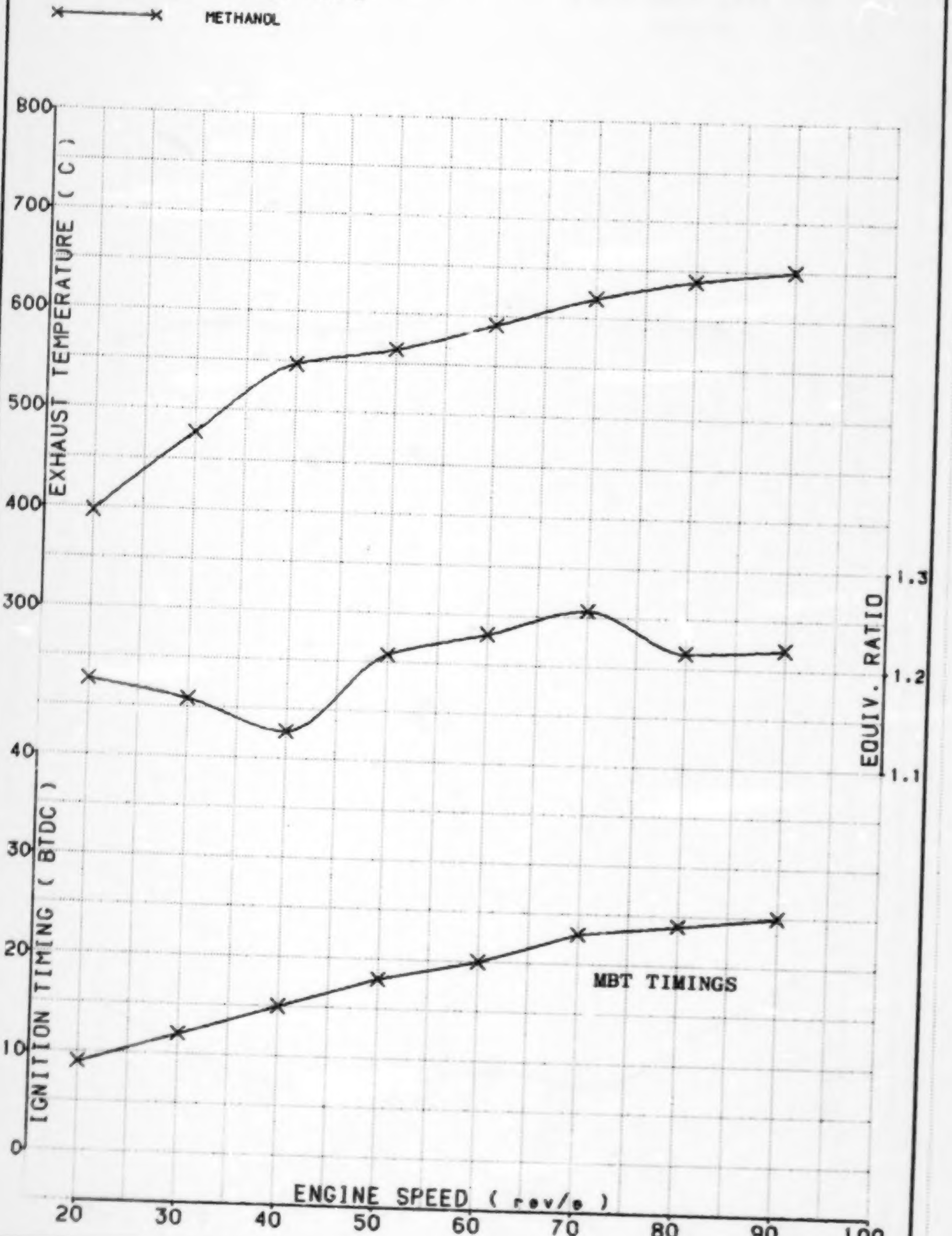
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
FULL LOAD POWER CURVE



RICARDO

Fig.No. 22
Drg.No.
Date: 16 Aug 1982

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
FULL LOAD POWER CURVE

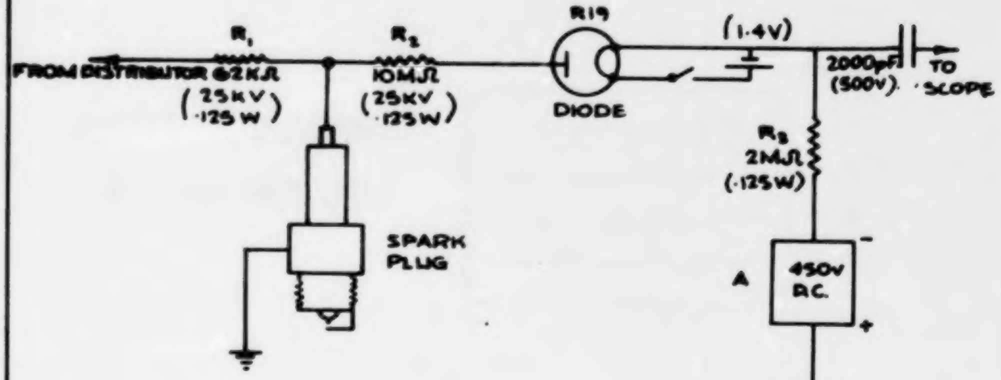


CRM/T.W.

RICARDO

FIG. No. 23
Drg. No. 39774
Date FEB '63

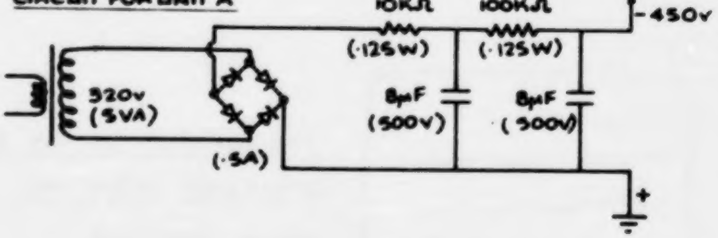
FIRING PLUG IONISATION SYSTEM



R19 DIODE

P.I.V. 25KV
FILAMENT VOLTAGE 1·25V
FILAMENT CURRENT 200mA
ANODE/FILAMENT CAPACITY 1pF

CIRCUIT FOR UNIT A



JPM LTD.

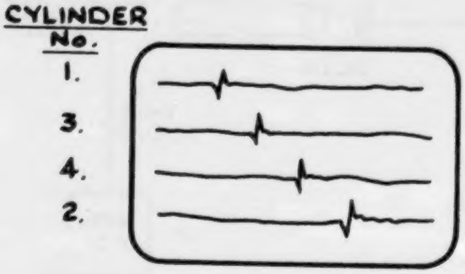
6448MT

IM.B.

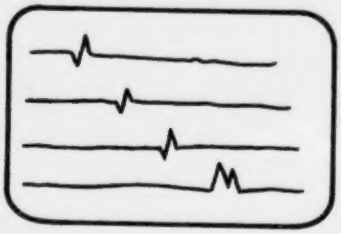
RICARDO

FIG. No. 24
Drg. No. S9825
Date Feb '83

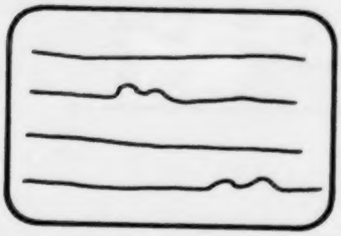
EXAMPLES OF TRAÇES OBTAINED FROM PRE-IGNITION DETECTION SYSTEM.



NORMAL COMBUSTION
- NO PRE-IGNITION



PRE-IGNITION IN No. 2
CYLINDER WITH SPARK
PLUGS STILL FIRING



PRE-IGNITION IN Nos. 2 & 3
CYLINDER WITH NO
SPARK IGNITION.

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/M.B.

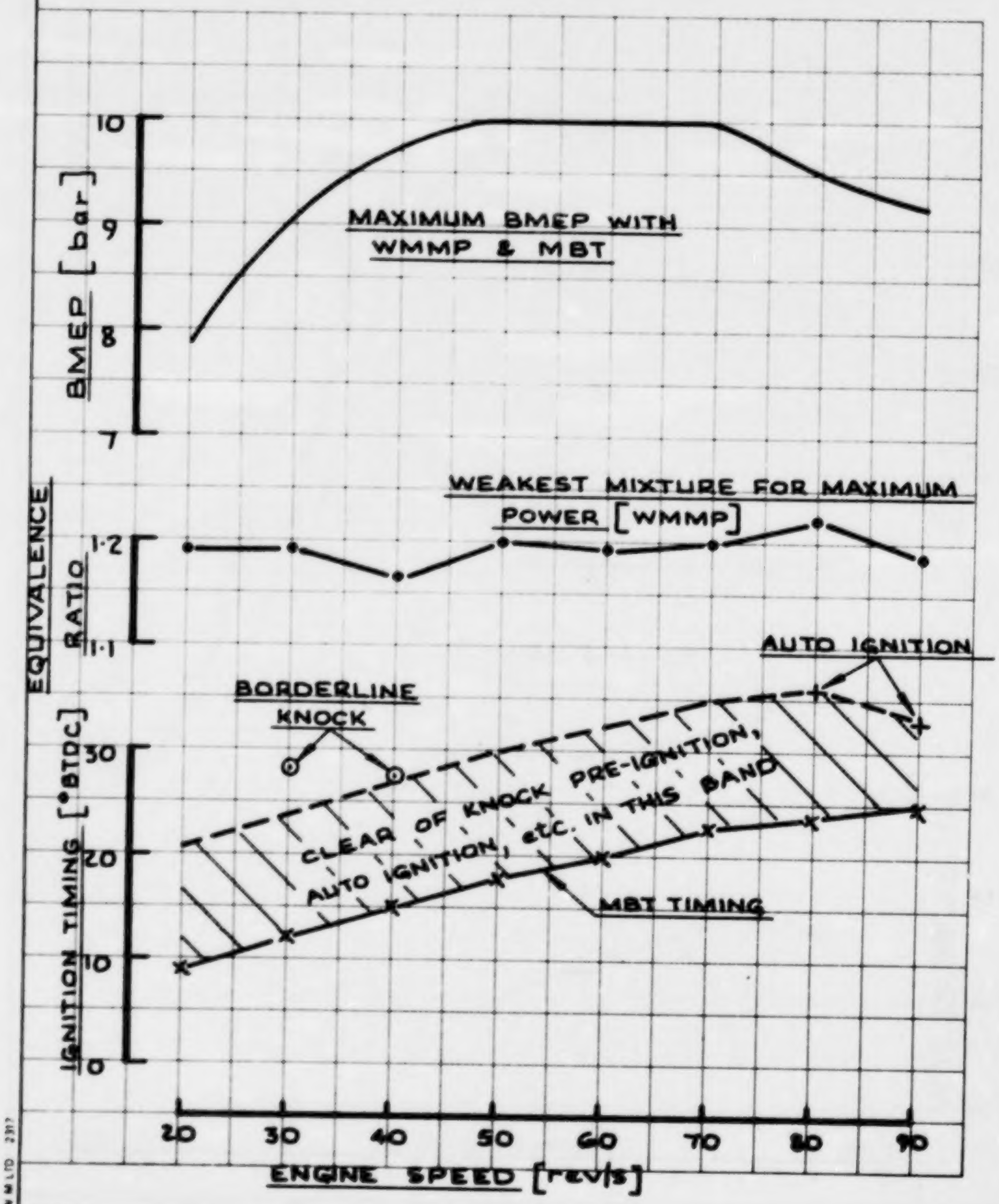
RICARDO

FIG. No. 25
Drg. No. D50039
Date Feb '83

EPA 1·5ℓ HRCC ENGINE

KNOCK AND PRE-IGNITION CHARACTERISTICS WITH METHANOL FUEL

CHAMPION BN60Y SPARK PLUGS

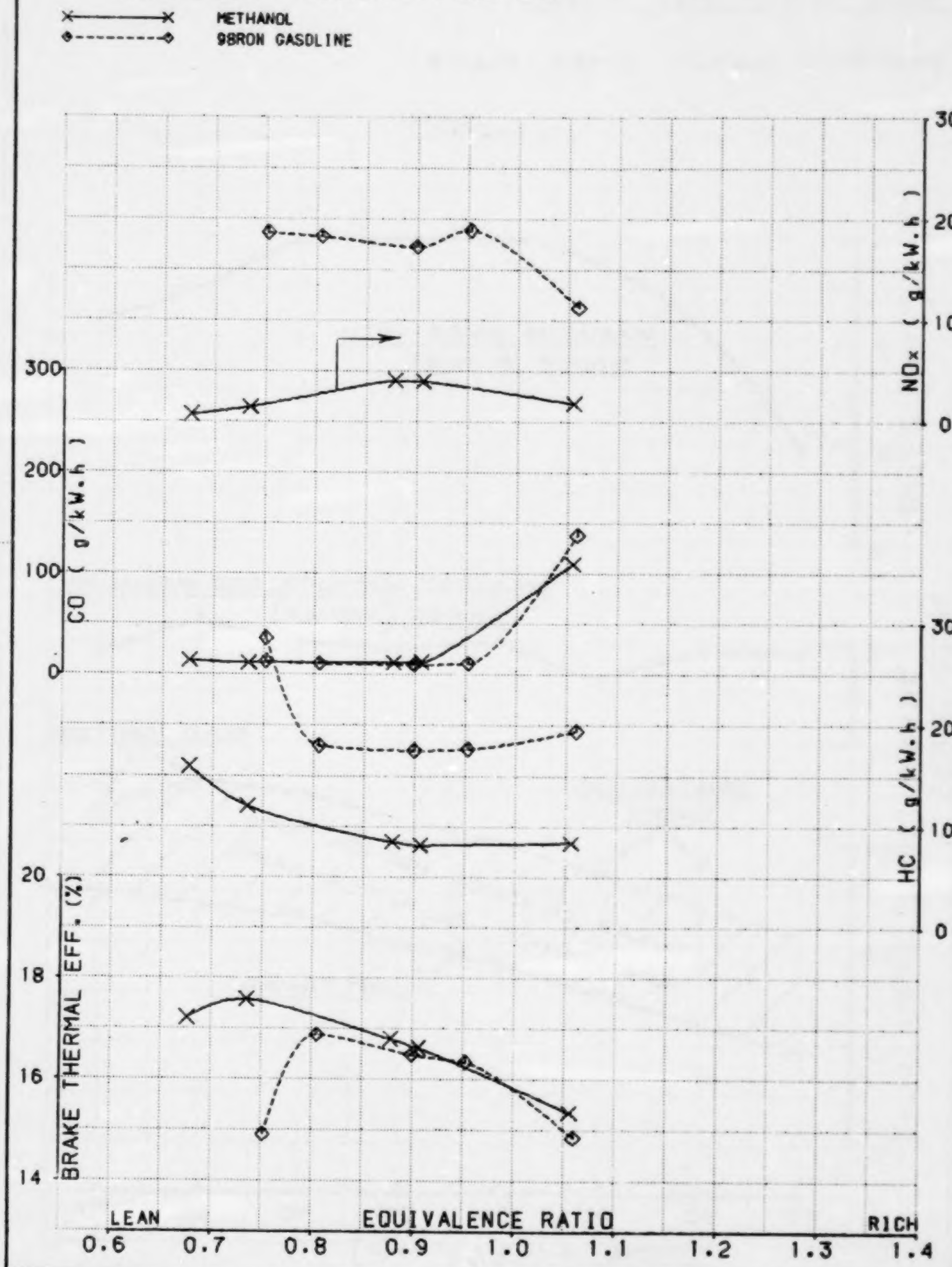


W M LTD 2317

RICARDO

Fig.№ 26
Drg.No.
Date: 14 Sep 1982

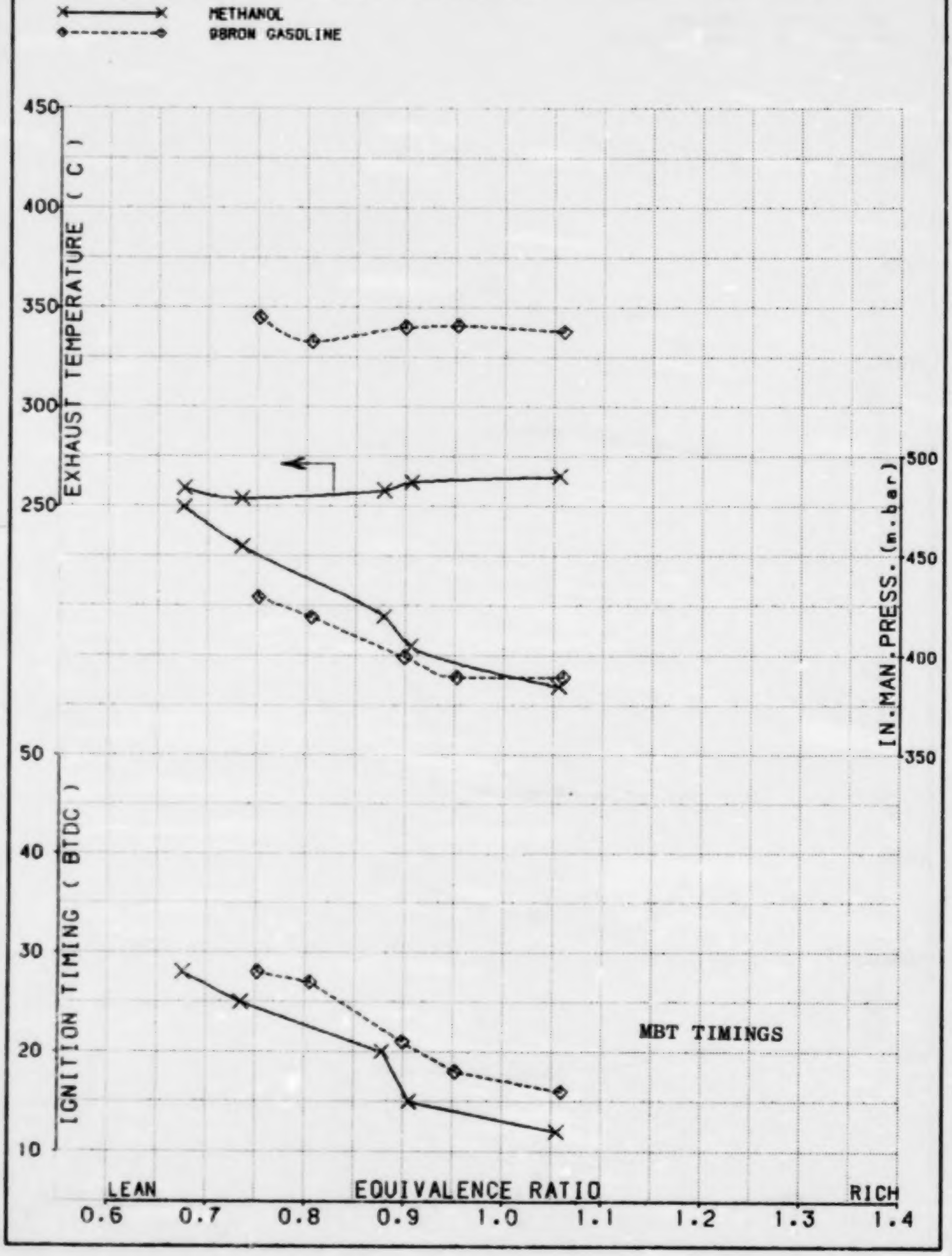
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP • 20REV/S 1.5 BMEP BAR

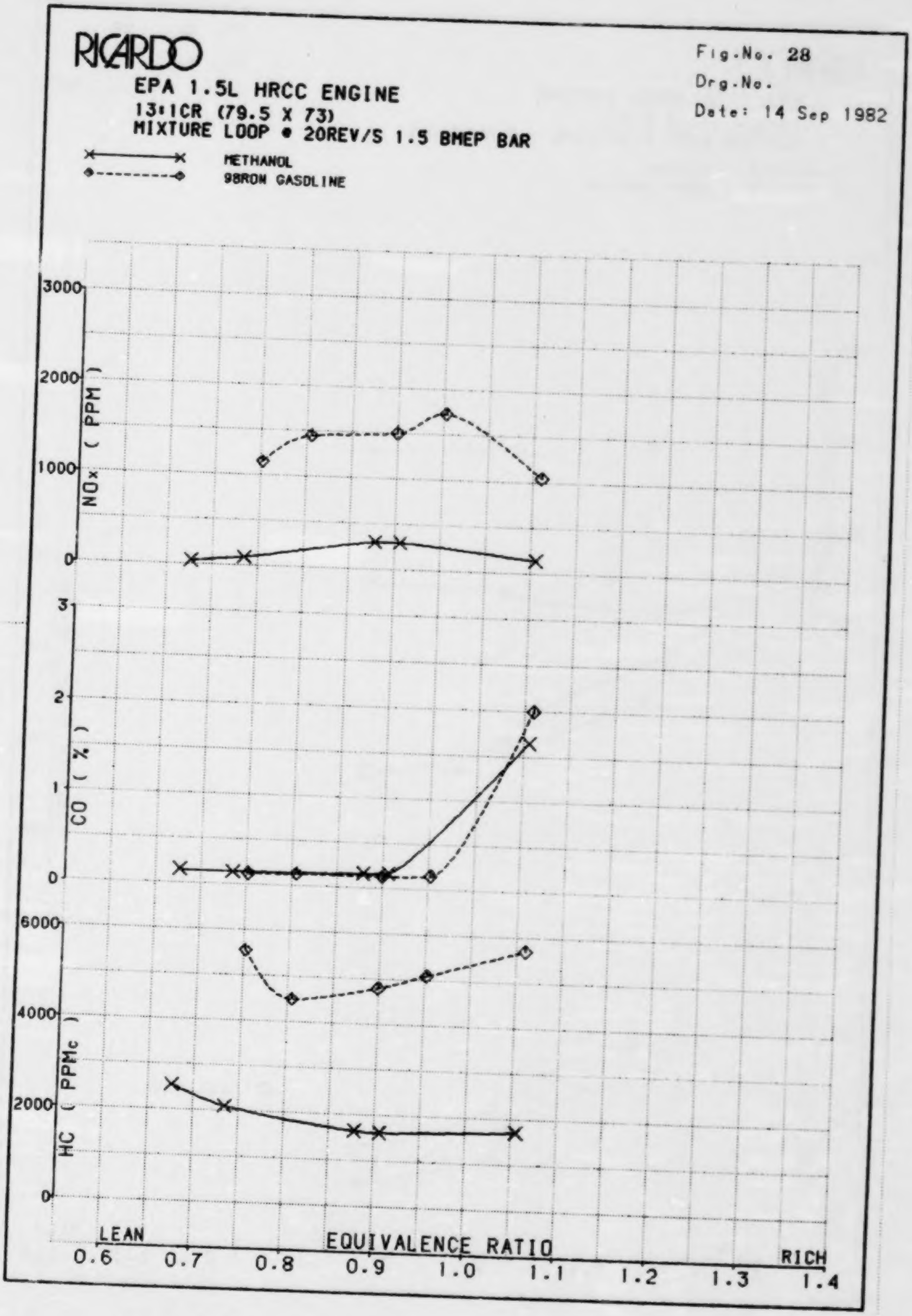


RICARDO

Fig.No. 27
Drg.No.
Date: 14 Sep 1982

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 20REV/S 1.5 BMEP BAR

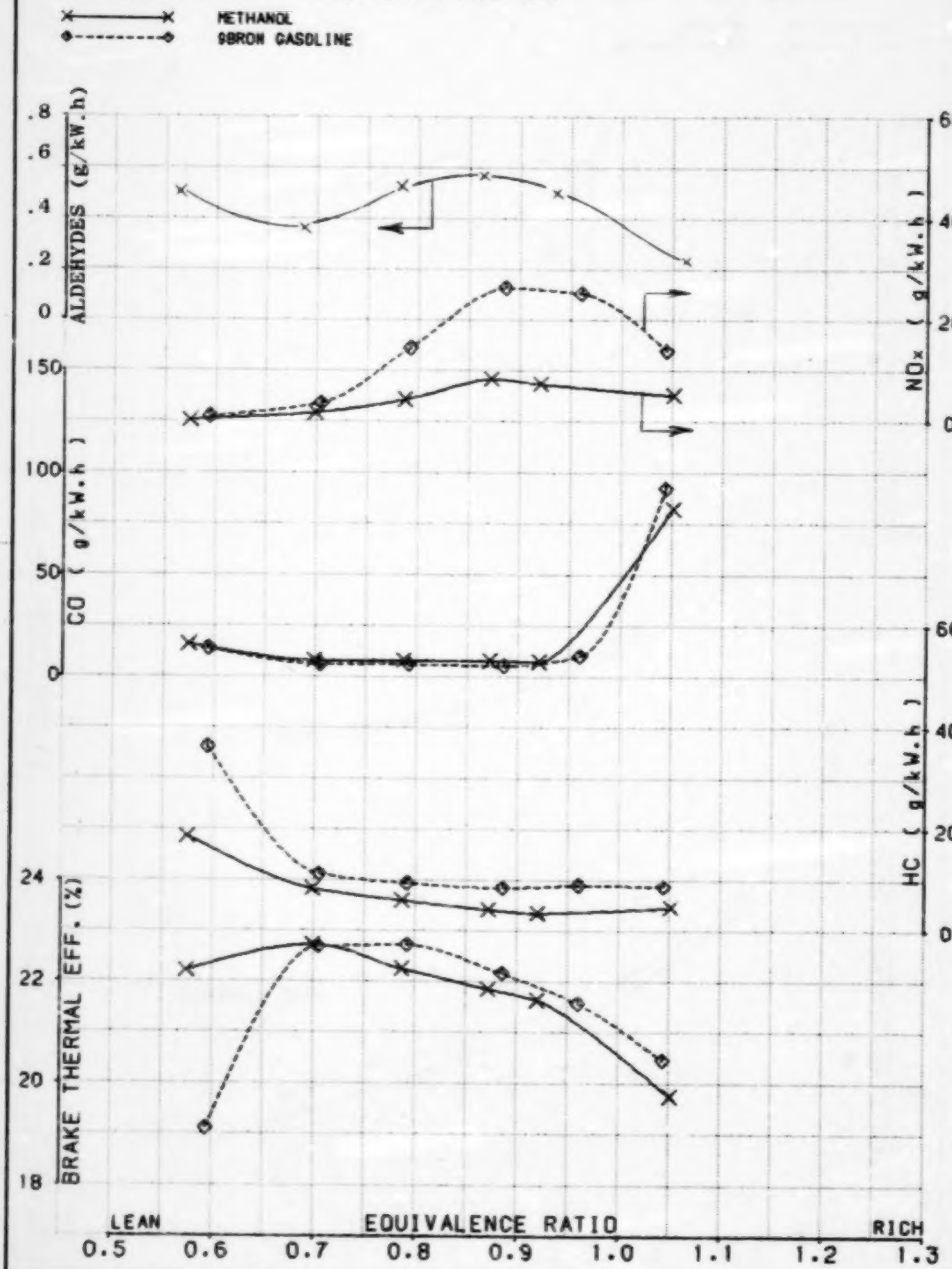



RICARDO
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP ● 20REV/S 1.5 BMEP BAR
Fig.No. 28
Drg.No.
Date: 14 Sep 1982
METHANOL
98RON GASOLINE
NOx (PPM)
3000
2000
1000
0
CO (%)
3
2
1
0
HC (PPMc)
6000
4000
2000
0
LEAN
EQUIVALENCE RATIO
RICH
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4

RICARDO

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 40REV/S 2.5 BMEP BAR

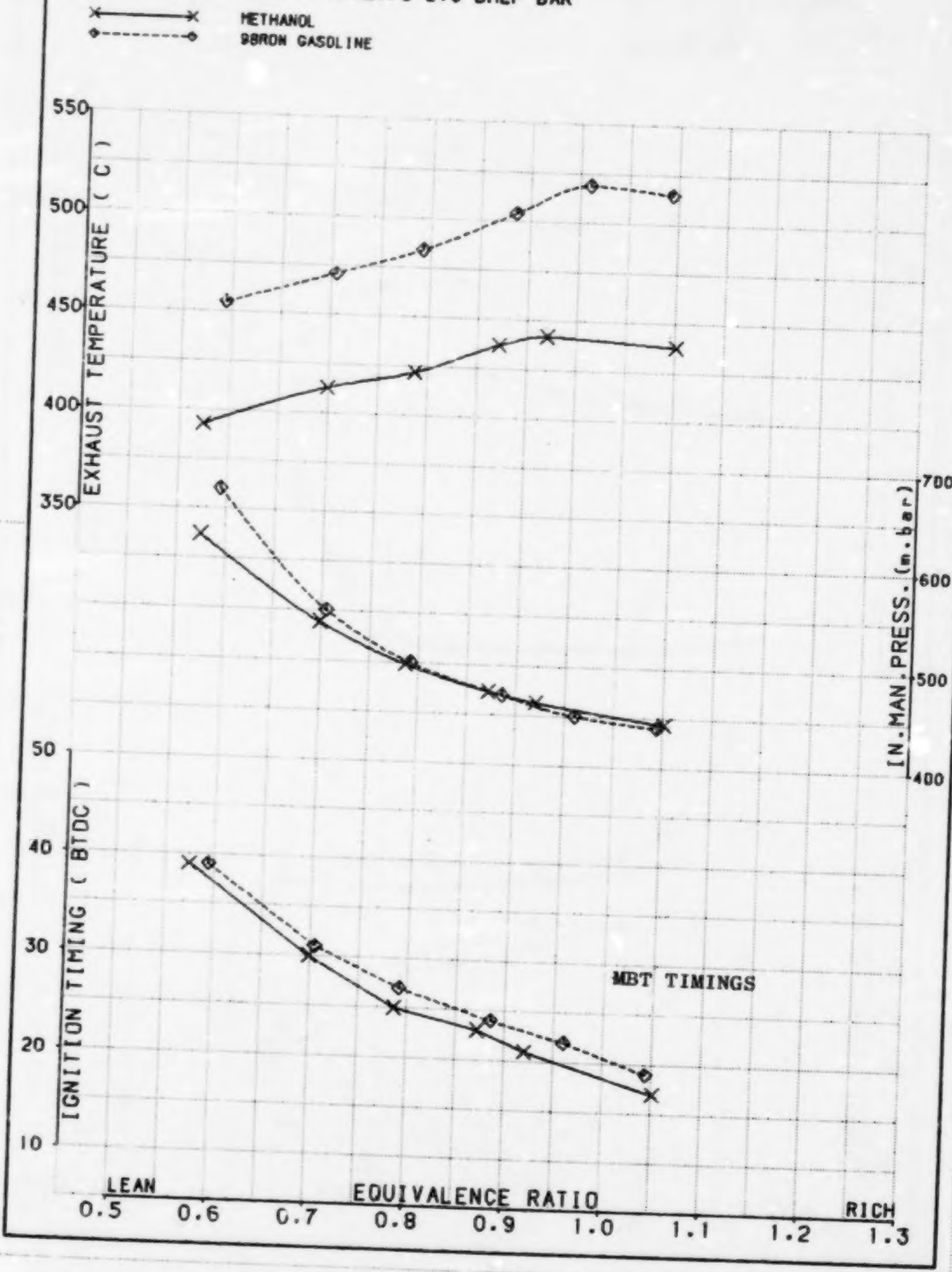
Fig.No. 29
Drg.No.
Date: 8 Sep 1982



RICARDO

Fig.No. 30
Drg.No.
Date: 8 Sep 1982

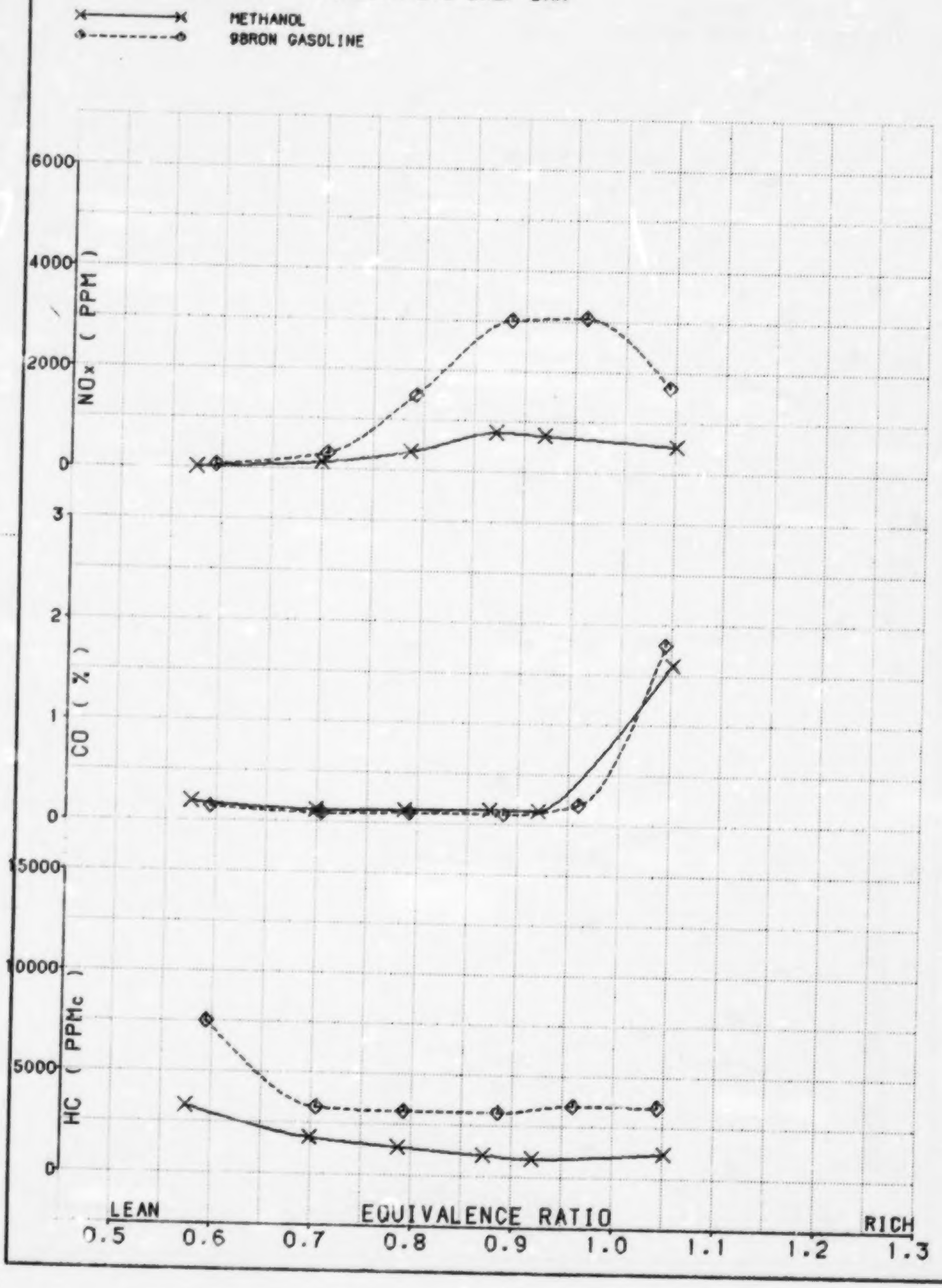
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 40REV/S 2.5 BMEP BAR



RICARDO

Fig.No. 31
Drg.No.
Date: 8 Sep 1982

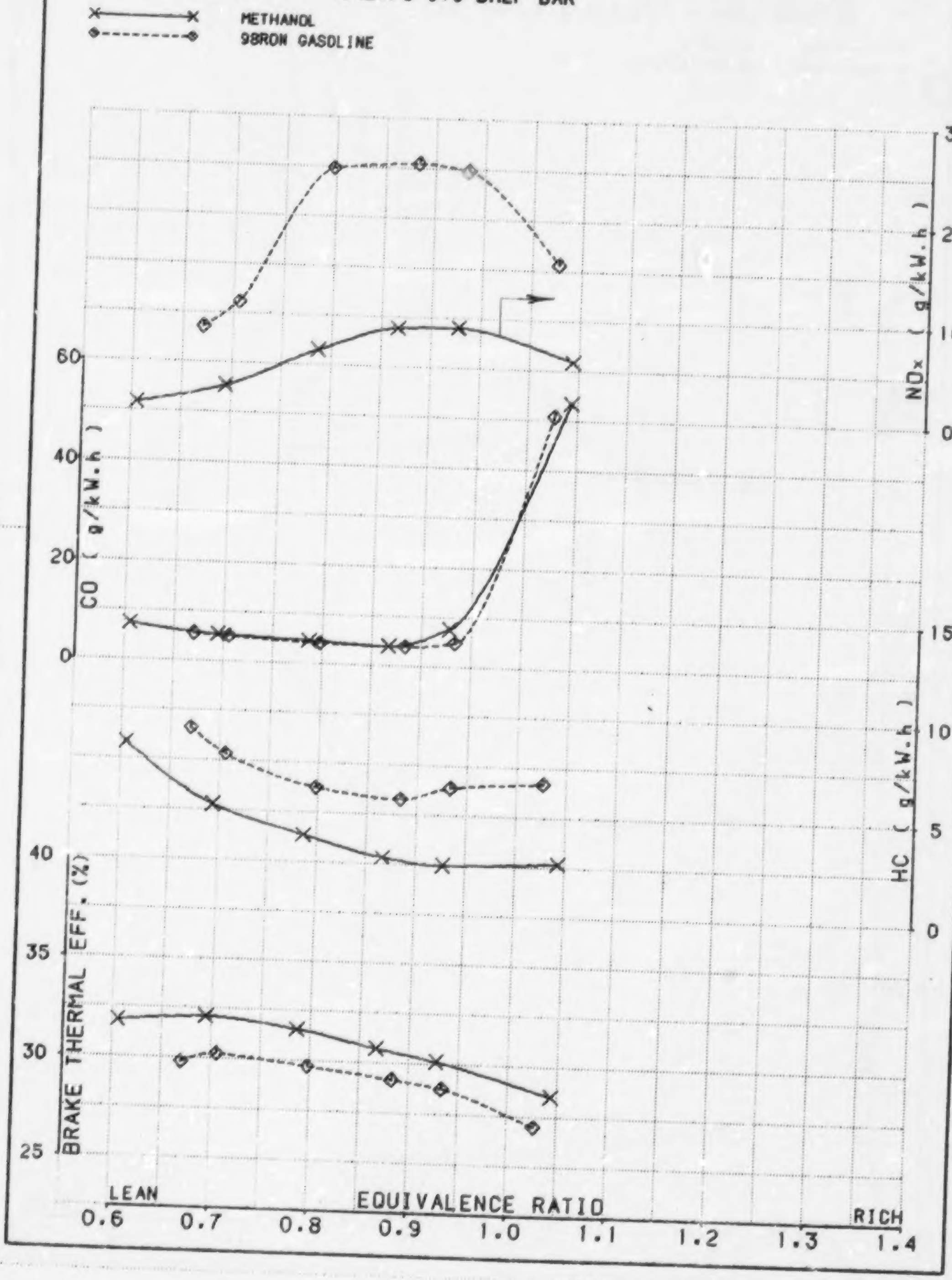
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP • 40REV/S 2.5 BMEP BAR



RICARDO

Fig.No. 32
Drg.No.
Date: 14 Sep 1982

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 40REV/S 5.5 BMEP BAR



RICARDO

Fig.No. 33

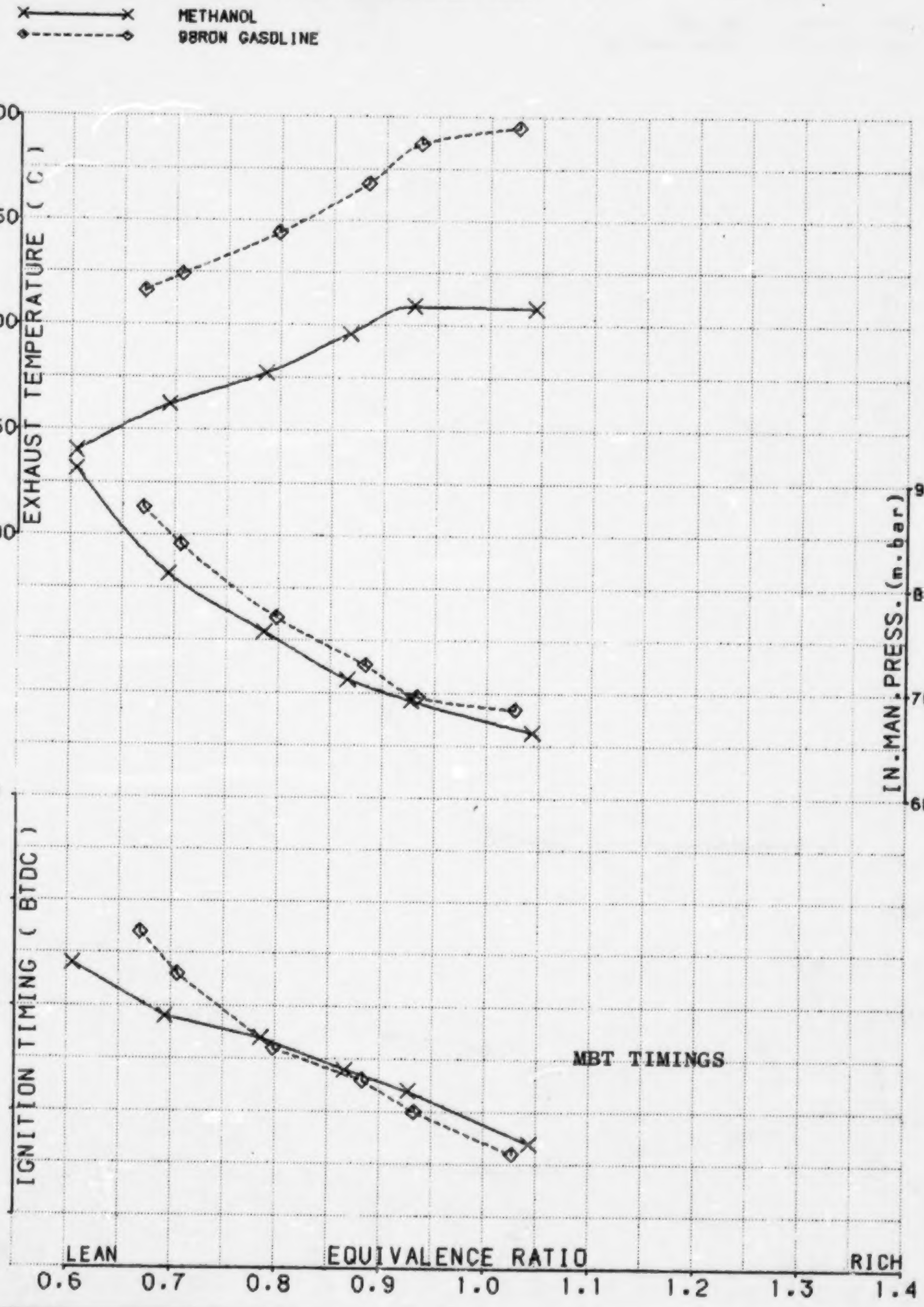
Drg.No.

Date: 14 Sep 1982

EPA 1.5L HRCC ENGINE

13:1CR (79.5 X 73)

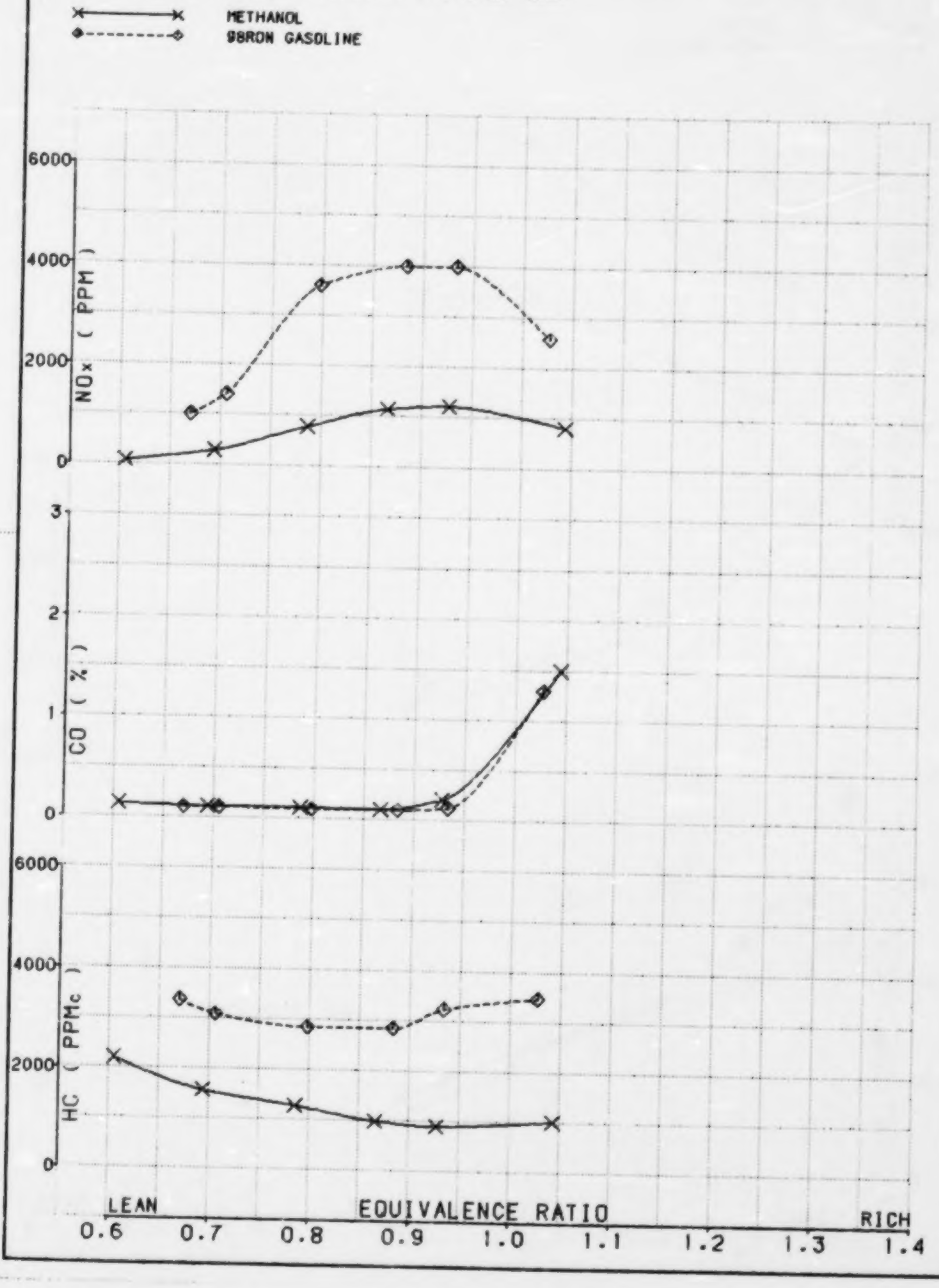
MIXTURE LOOP ● 40REV/S 5.5 BMEP BAR



RICARDO

Fig.No. 34
Drg.No.
Date: 14 Sep 1982

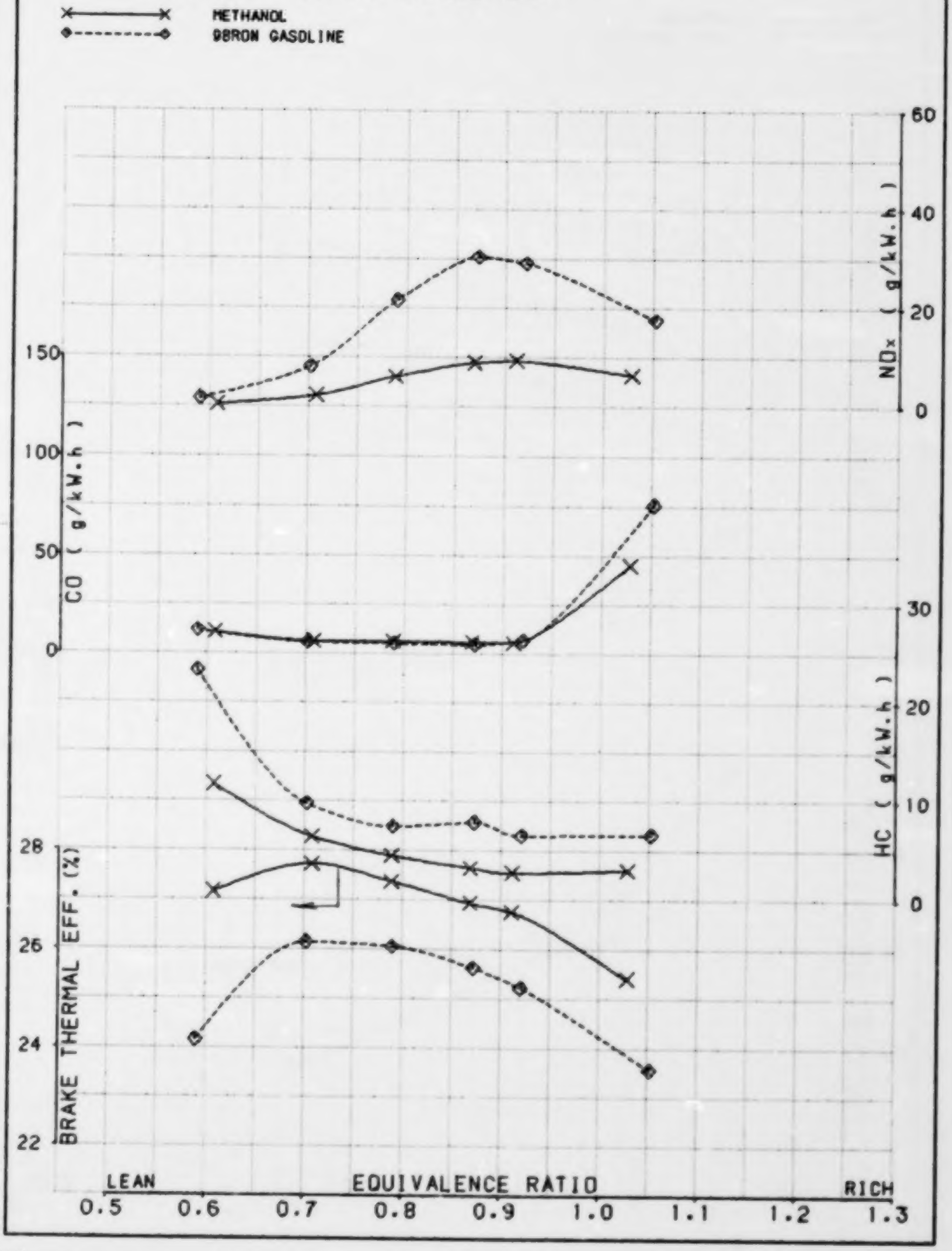
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP ● 40REV/S 5.5 BMEP BAR



RICARDO

Fig.No. 35
Drg.No.
Date: 14 Sep 1982

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP • 60REV/S 4.0 BMEP BAR

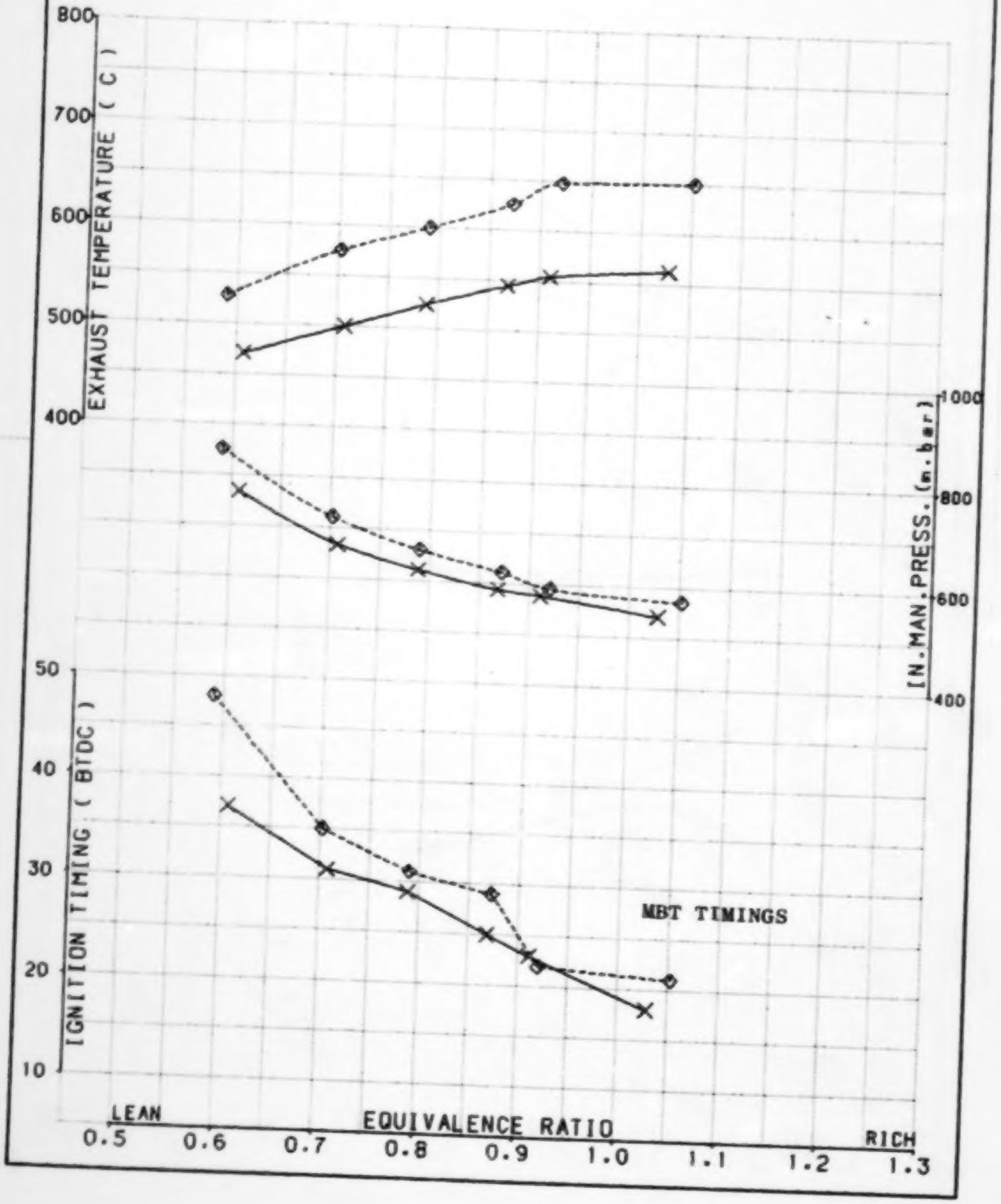


RICARDO

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 60REV/S 4.0 BMEP BAR

Fig.No. 36
Drg.No.
Date: 14 Sep 1982

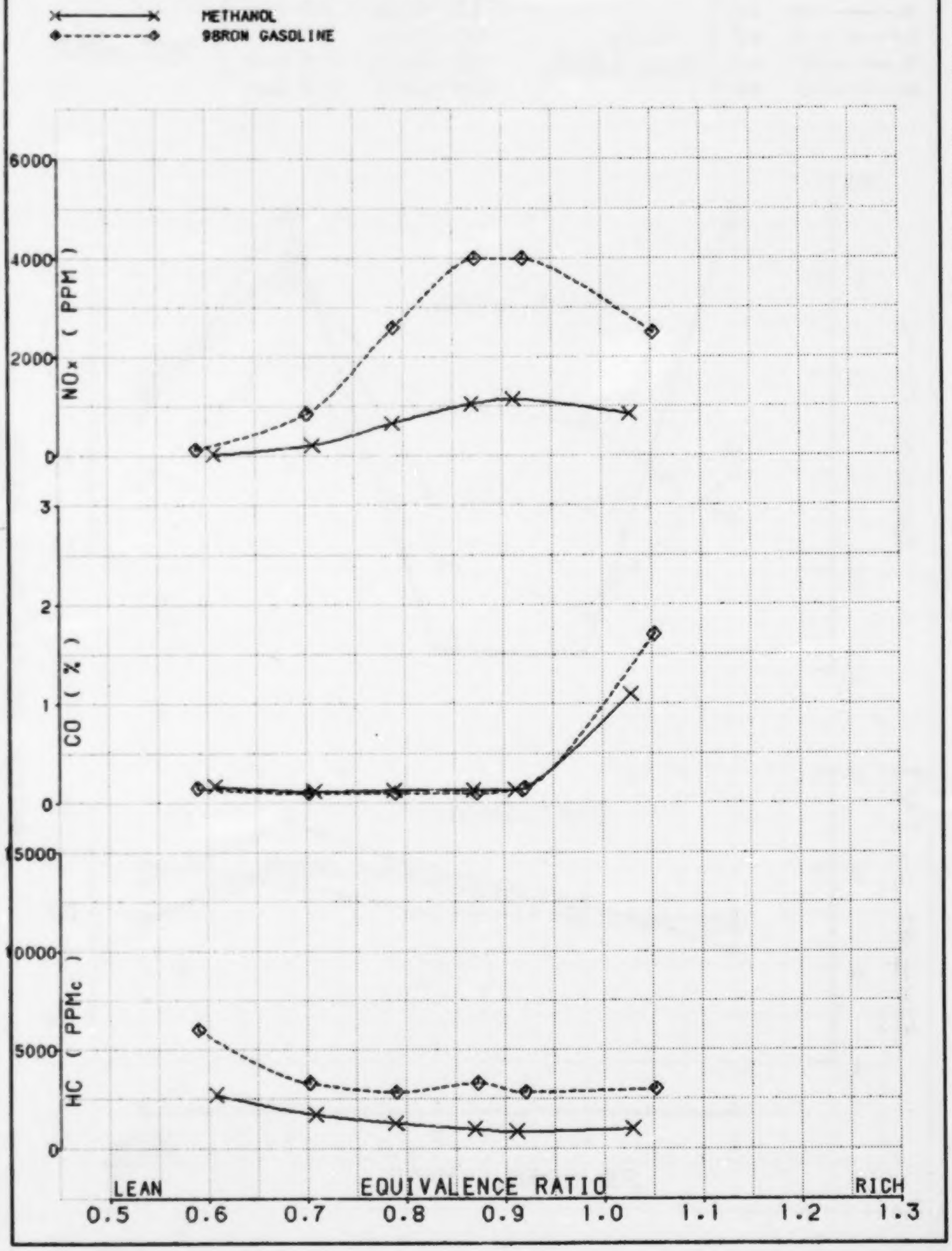
×——× METHANOL
◇- - -◇ 98RON GASOLINE



RICARDO

Fig.No. 37
Drg.No.
Date: 14 Sep 1982

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP @ 60REV/S 4.0 BMEP BAR

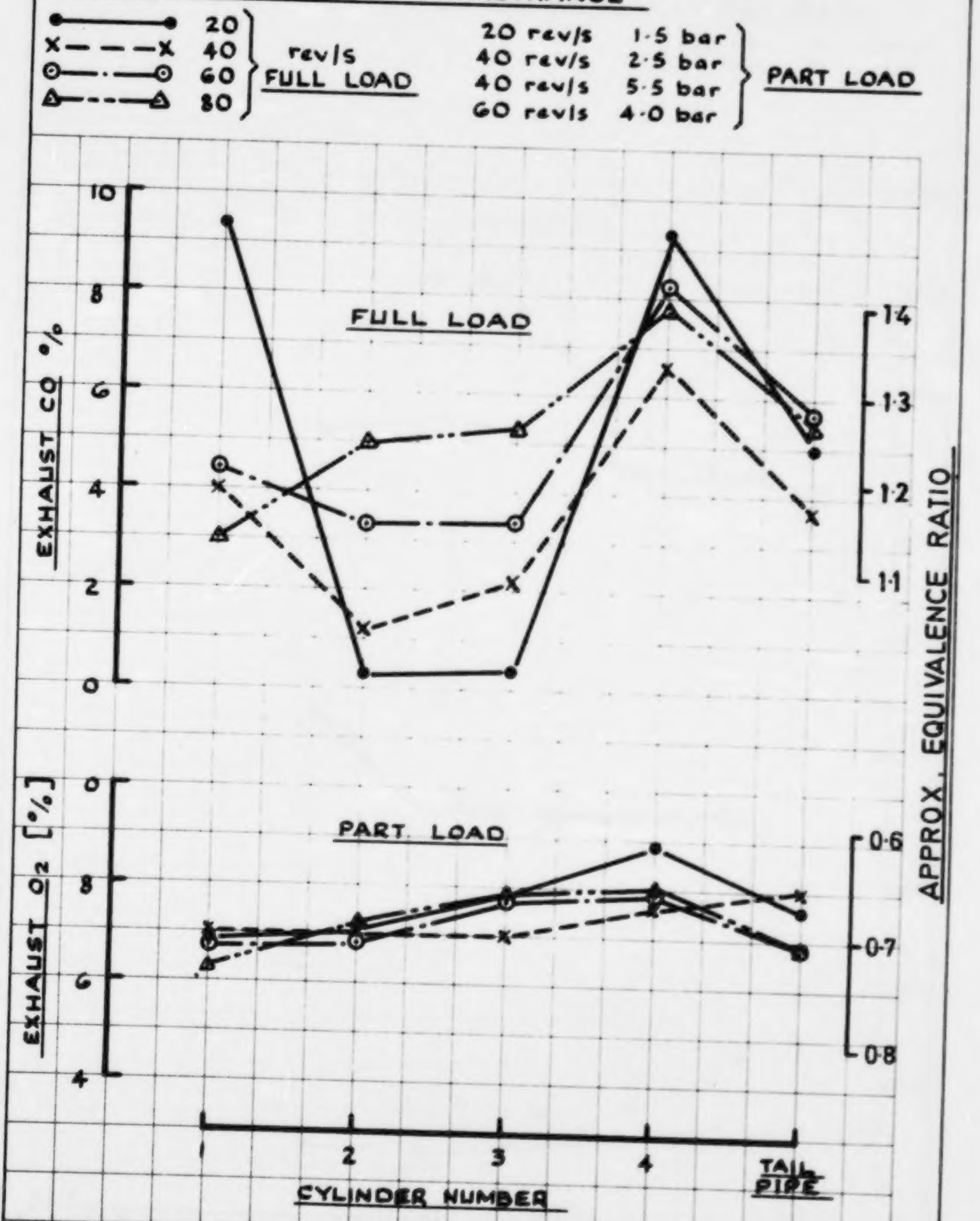


/M.B.

RICARDO

FIG. No. 38
Drg. No. D50041
Date Feb '83

HRCC ENGINE 79·5 x 73·4 mm. - 1·5 l.
MIXTURE DISTRIBUTION - METHANOL



W M LTD 2317

RICARDO

C.R.M./L.M.

FIG. No. 30

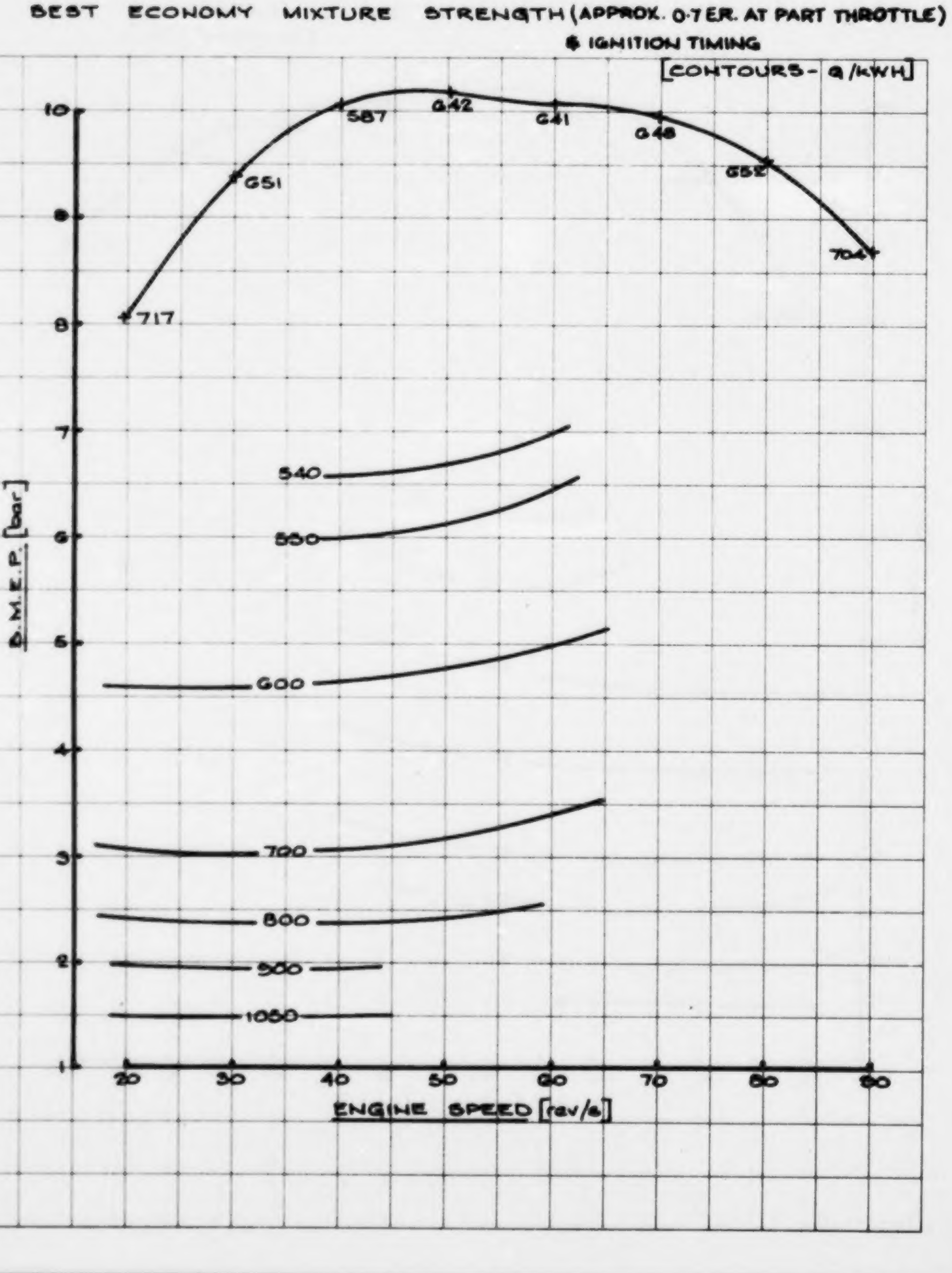
Drg. No. D 50002

Date MARCH '85

EPA 1·5L HRCC ENGINE

B.S.F.C. CONTOURS

BEST ECONOMY MIXTURE STRENGTH (APPROX. 0·7 E.R. AT PART THROTTLE)
& IGNITION TIMING



W M LTD 2317

RICARDO

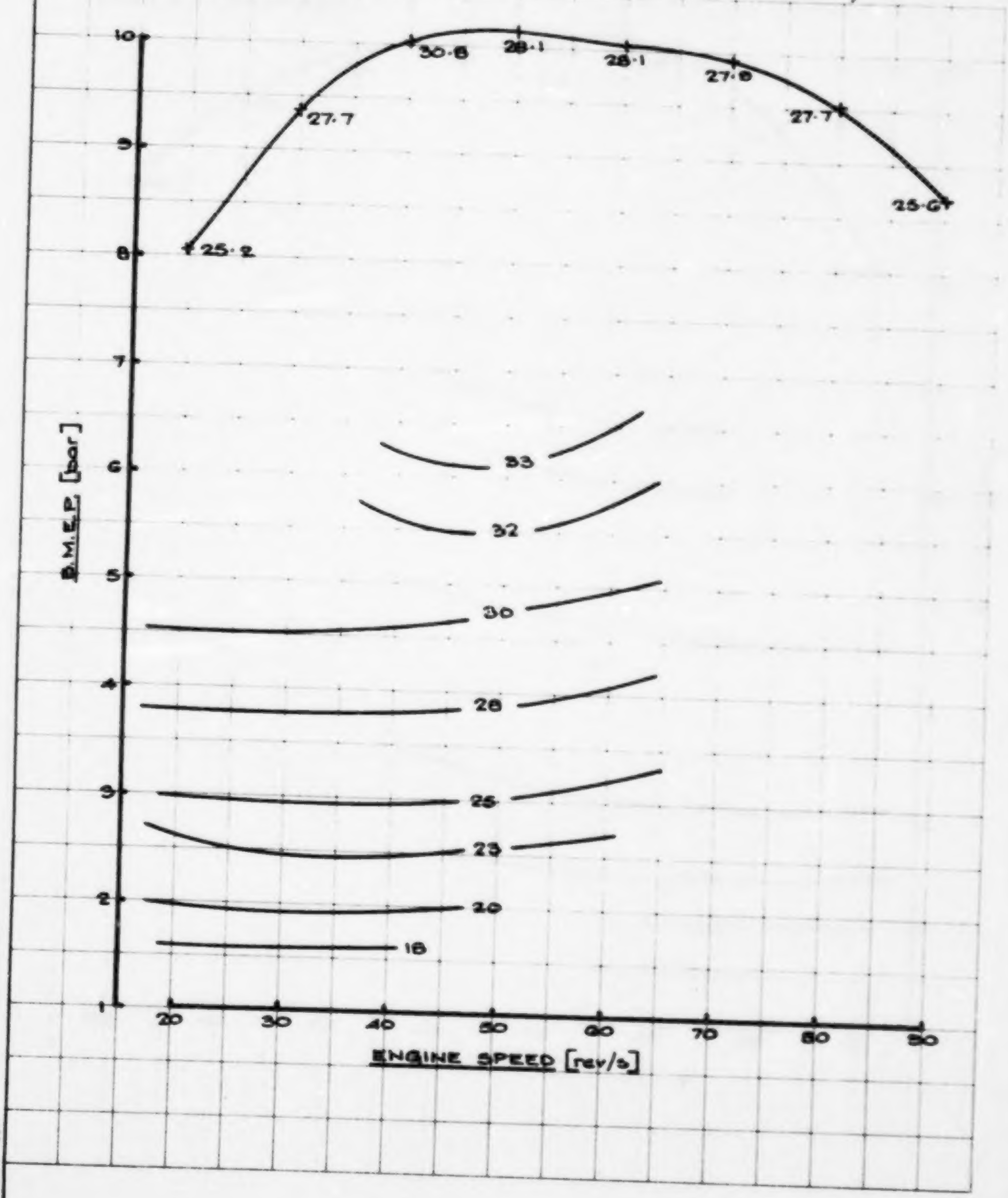
C.R.M. /L.M.

FIG. No. 40
Drg. No. D 30003
Date MARCH '83.

EPA 1·5L HRCC ENGINE

BRAKE THERMAL EFFICIENCY CONTOURS

BEST ECONOMY MIXTURE STRENGTH & IGNITION TIMING
[CONTOURS - %]



W M LTD 2317

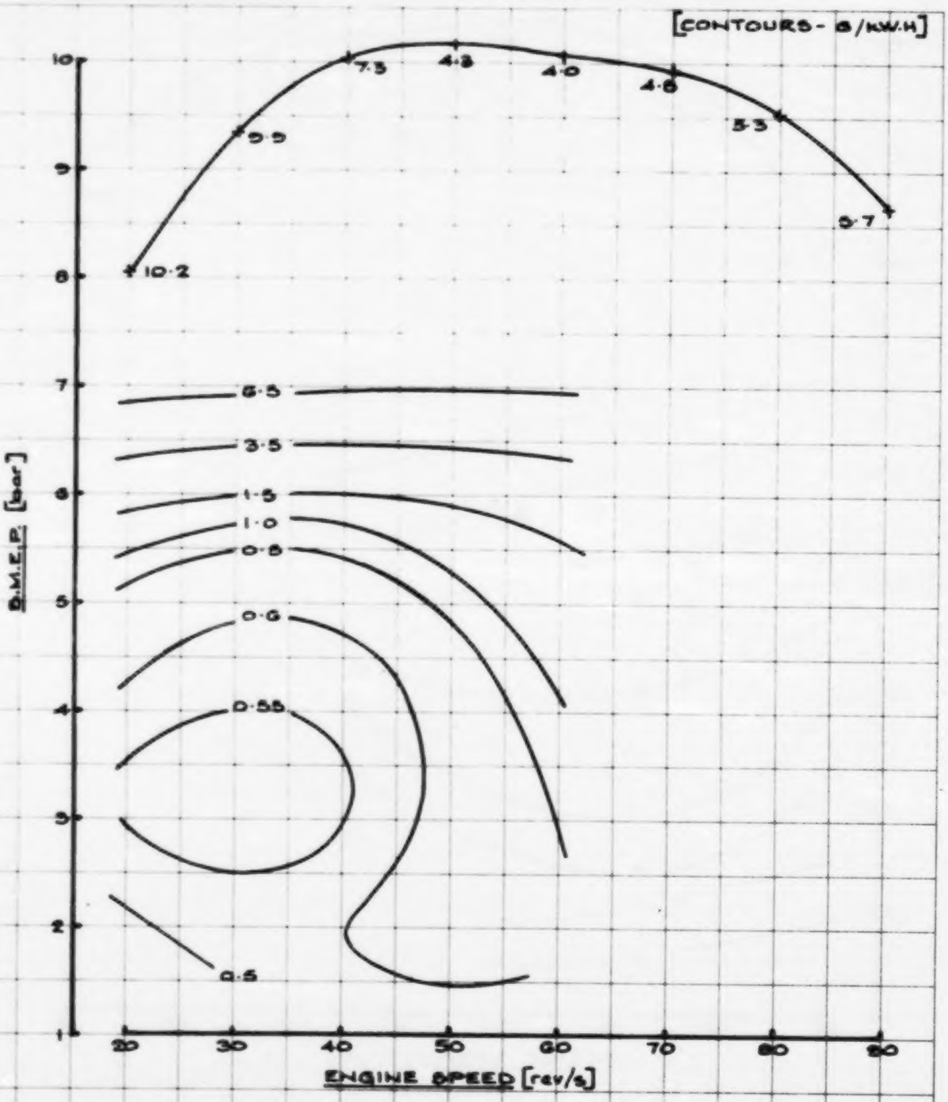
RICARDO

C.R.M. /L.M.
FIG. No. 41
Drg. No. D 60004
Date MARCH '83

EPA 1·6L HRCC ENGINE

NOx EMISSION CONTOURS

BEST ECONOMY MIXTURE STRENGTH & IGNITION TIMING.



W M LTD 2317

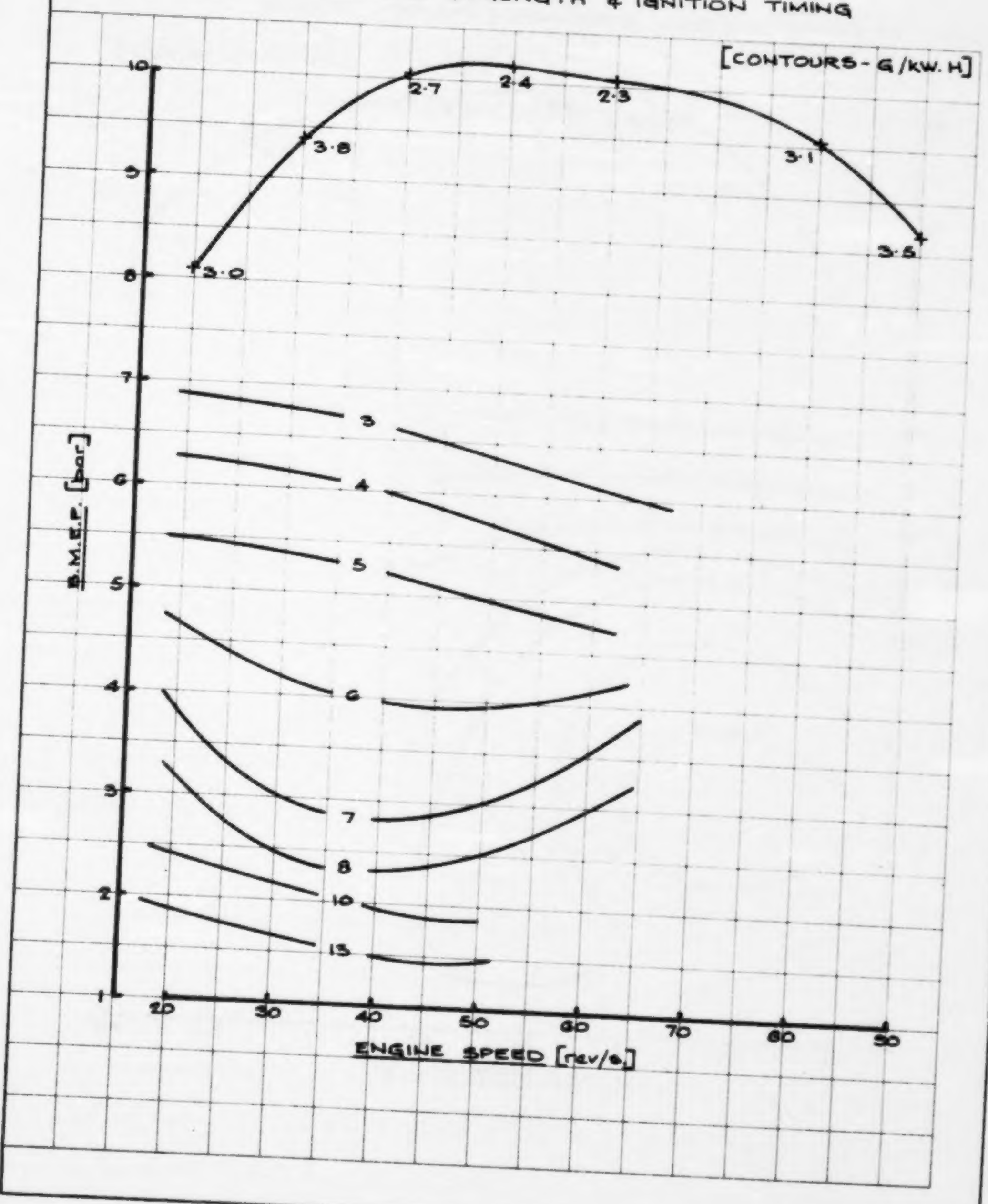
RICARDO

C.R.M. /L.M.
FIG. No. 42
Drg. No. D 50005
Date MARCH '83.

EPA 1·5L HRCC ENGINE

HC EMISSION CONTOURS

BEST ECONOMY MIXTURE STRENGTH & IGNITION TIMING



W M LTD 2317

C.R.M./L.M.

RICARDO

FIG. No. 43

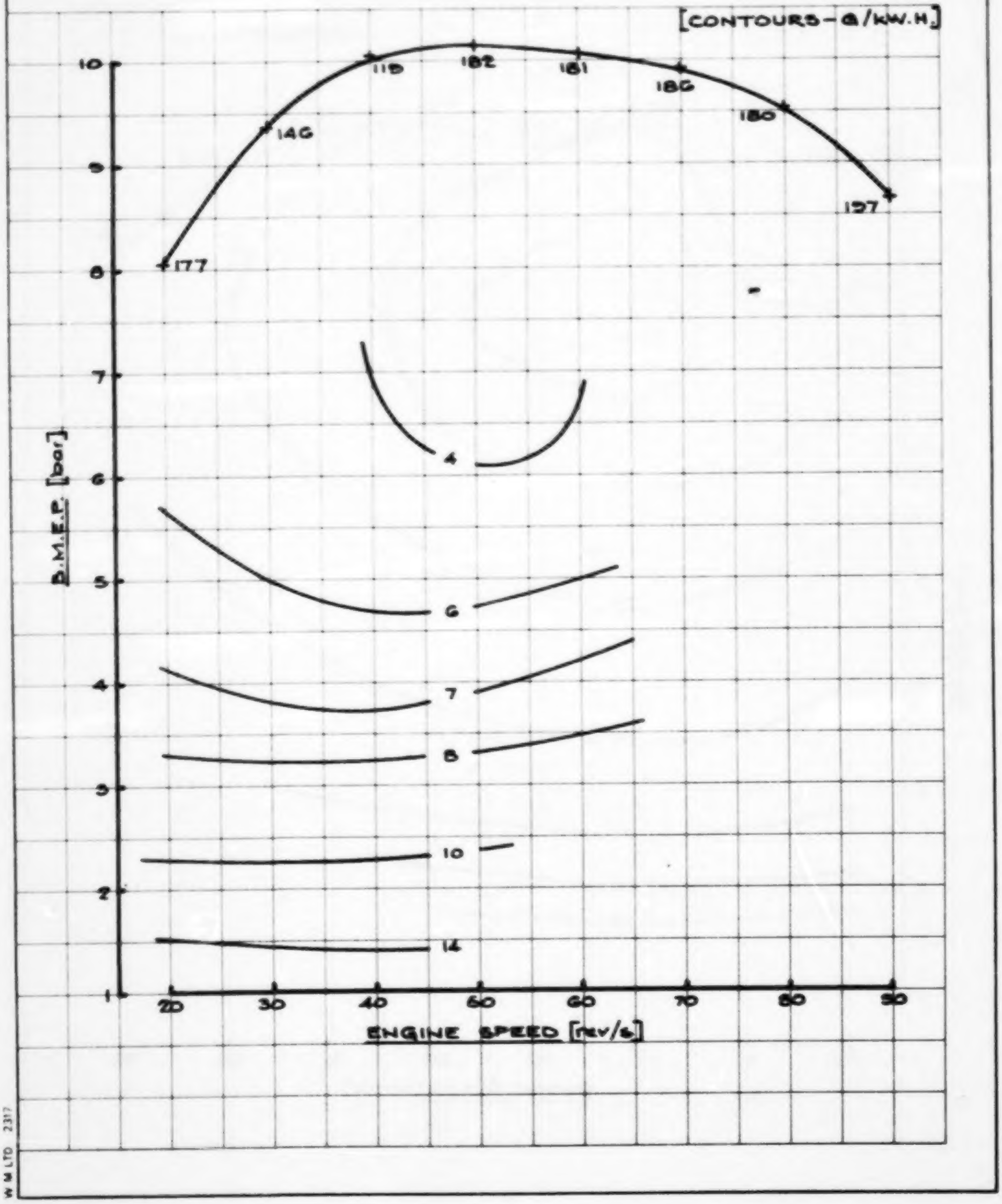
Drg. No. D 50006

Date MARCH '83

EPA 1·5L HRCC ENGINE

CO EMISSION CONTOURS

BEST ECONOMY MIXTURE STRENGTH & IGNITION TIMING

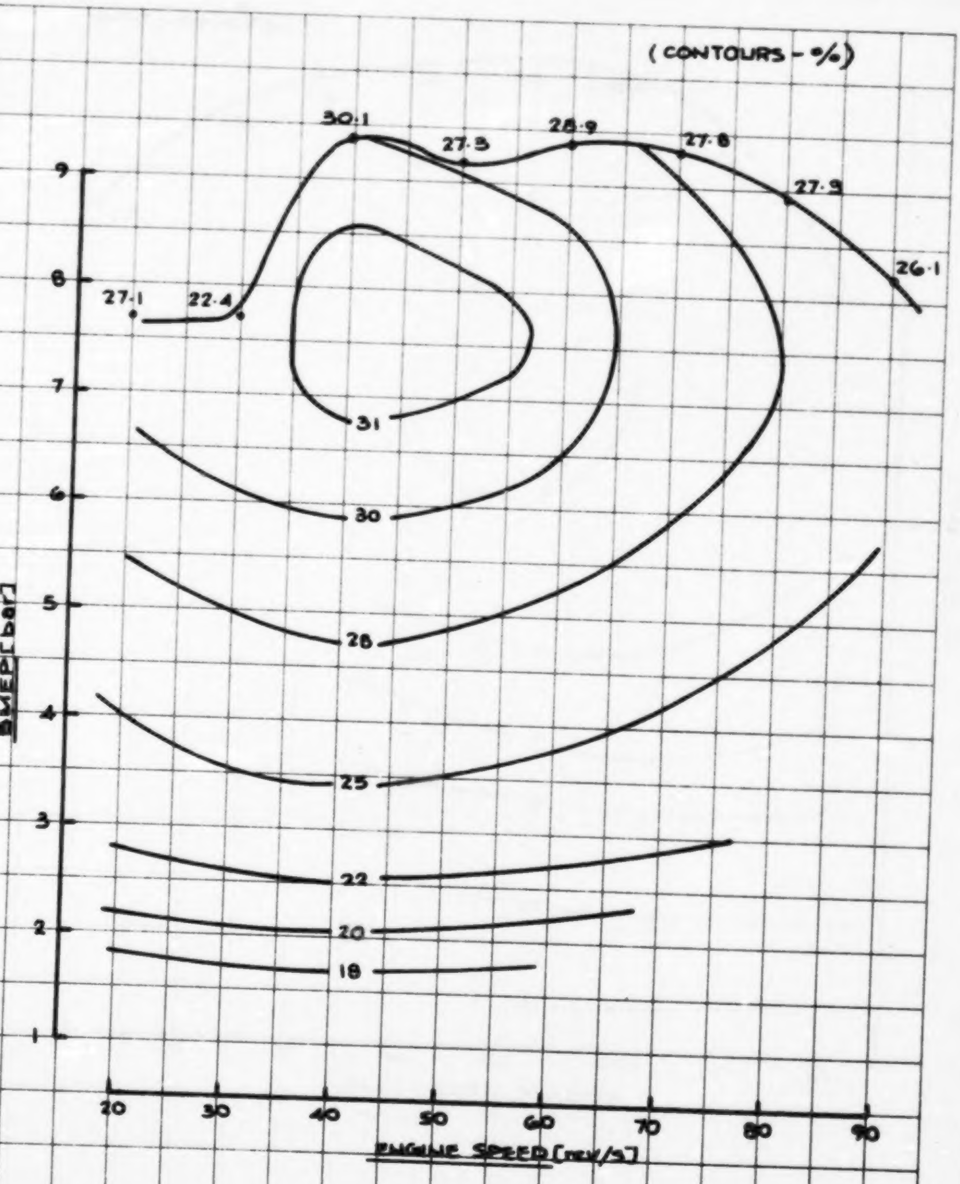


W M LTD 2317

RICARDO

C.R.M. / T.W.
FIG. No. 44
Drg. No. D49883
Date FEB '83

PRODUCTION VW 1·6L ENGINE
BRAKE THERMAL EFFICIENCY MAP
(AUTO FUELLING AUTO IGNITION NO EGR)



W M LTD 2317

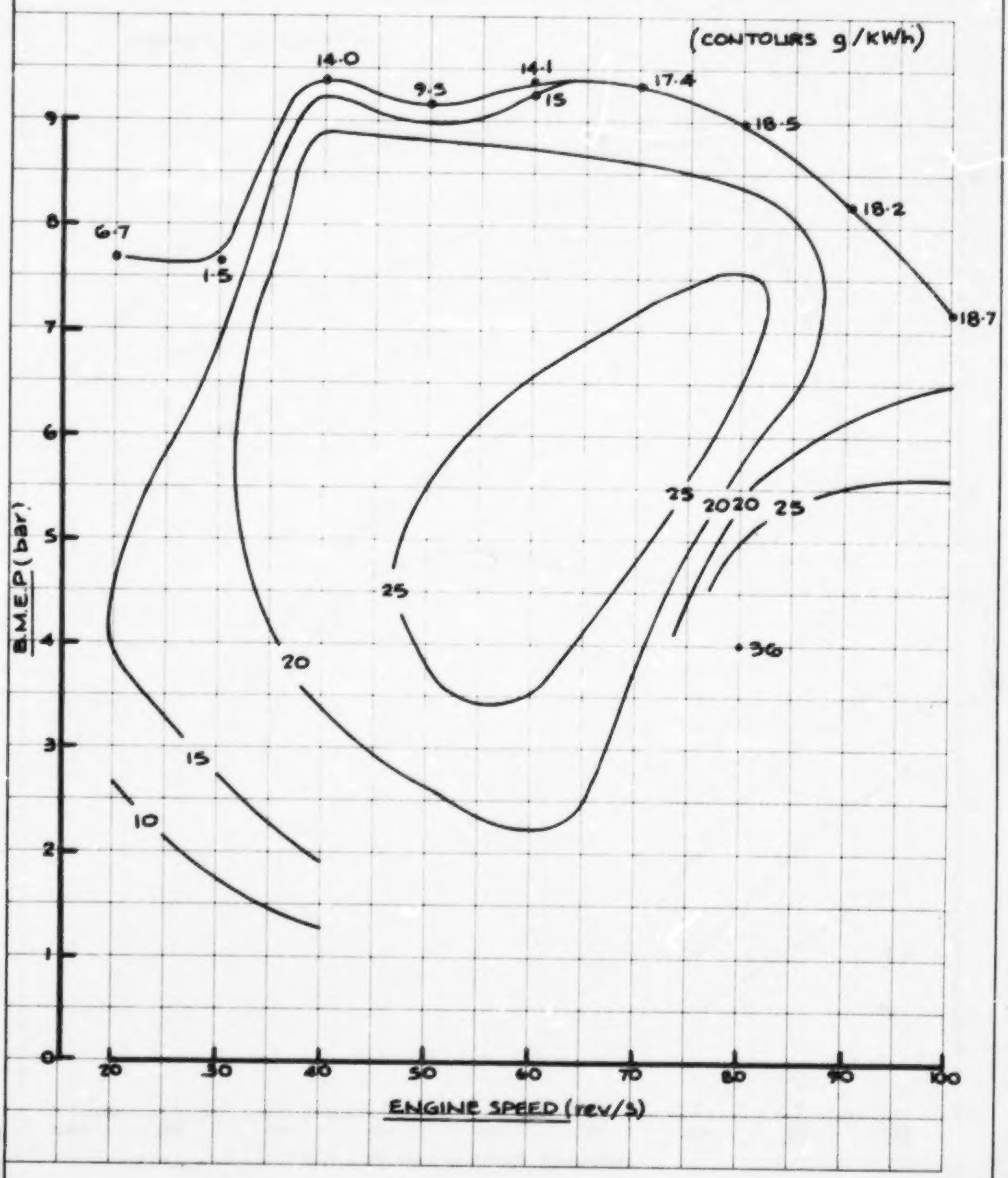
RICARDO

C.R.M./T.W.
FIG. No. 45
Drg. No. D49884
Date FEB '83

PRODUCTION VW 1·6L ENGINE

BRAKE SPECIFIC NOx MAP

(AUTO FUELLING, AUTO IGNITION, NO EGR)

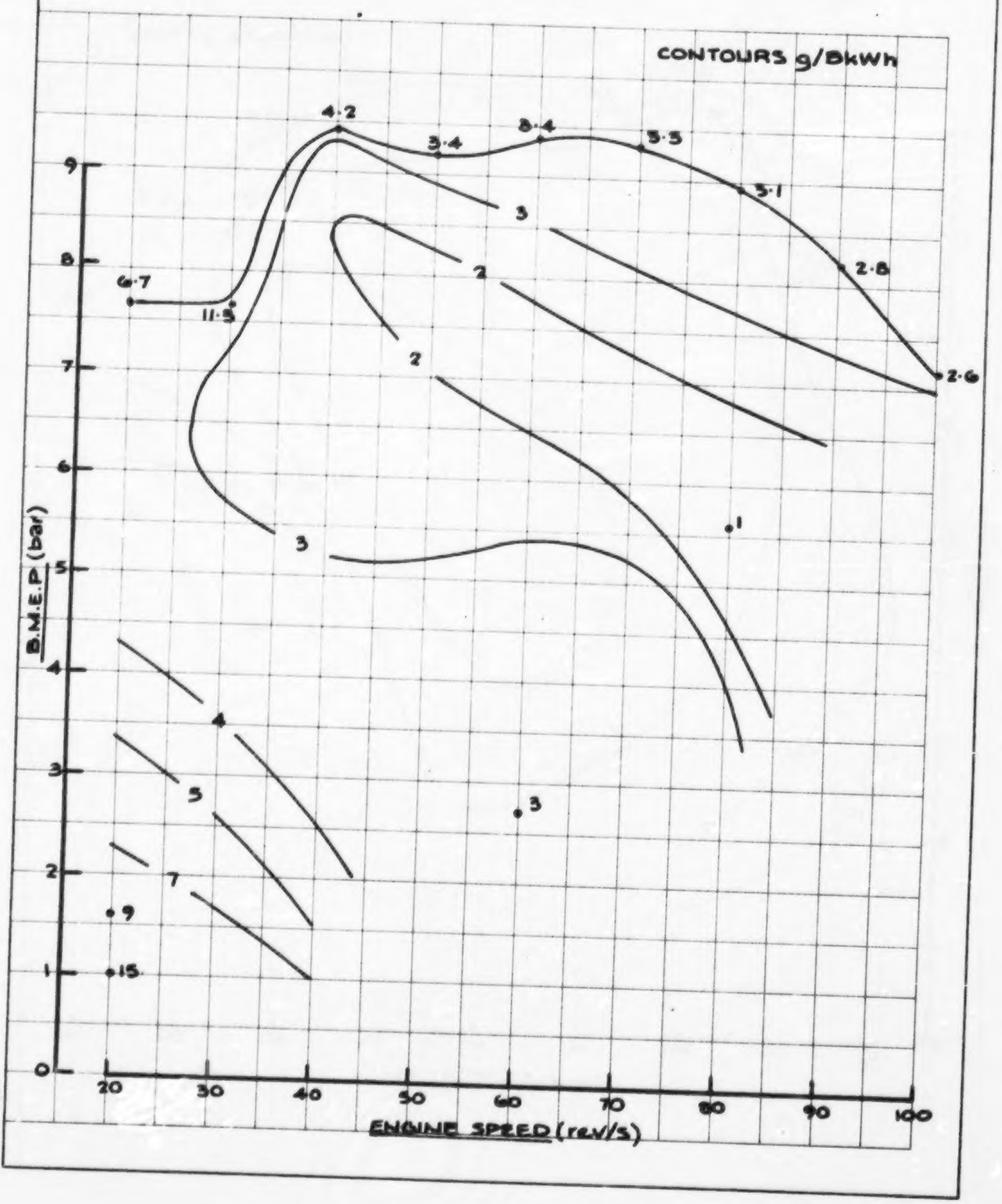


W M LTD 2317

RICARDO

C.R.M. / T.W.
FIG. No. 46
Drg. No. D49885
Date FEB '83

PRODUCTION VW 1·6L ENGINE
BRAKE SPECIFIC HC MAP
(AUTO FUELLING, AUTO IGNITION, NO EGR)



W.M. LTD 2317

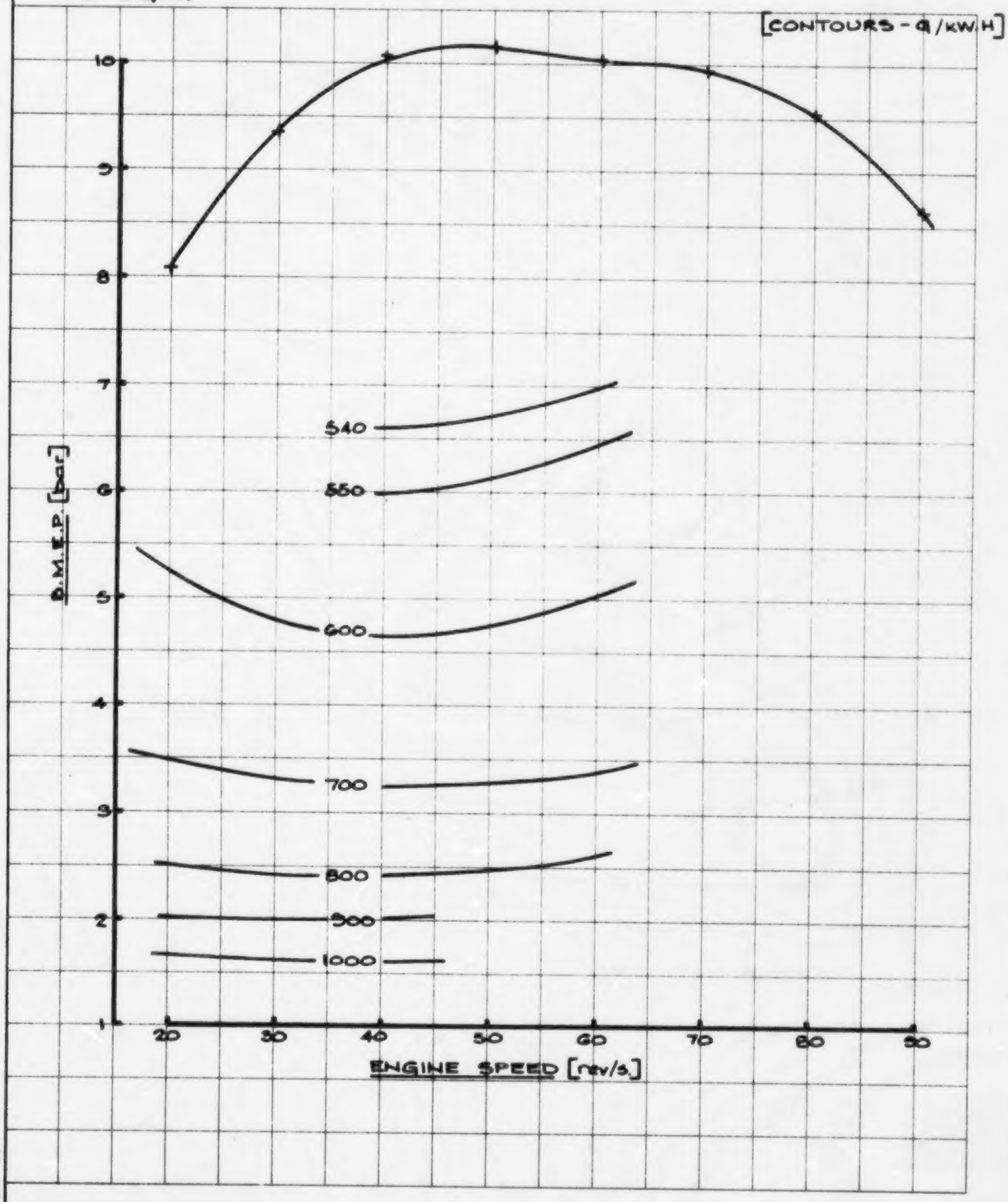
RICARDO

C.R.M. /L.M.
FIG. No. 47
Drg. No. D 50007
Date MARCH '83

EPA 1·5L HRCC ENGINE

B.S.F.C. CONTOURS

EQUIVALENCE RATIO ~ 0·8 OPTIMUM IGNITION TIMINGS
NO E.G.R.



W M LTD 2317

RICARDO

C.R.M. / L.M.

FIG. No. 46

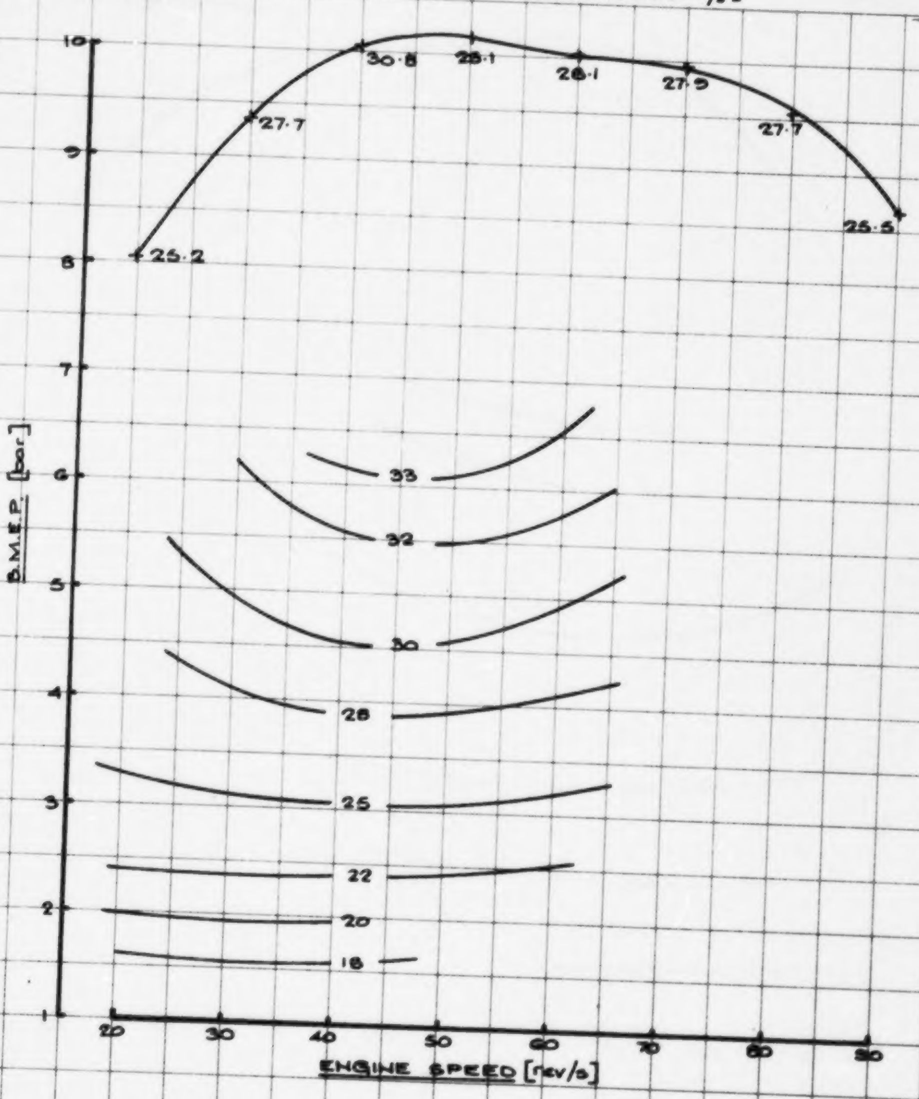
Drg. No. D50006

Date MARCH '83

EPA 1·5L HRCC ENGINE

BRAKE THERMAL EFFICIENCY CONTOURS

EQUIVALENCE RATIO ∽ 0·8 OPTIMUM IGNITION TIMINGS.
NO E.G.R. [CONTOURS - %]



W M LTD 2317

C.R.M. /L.M.

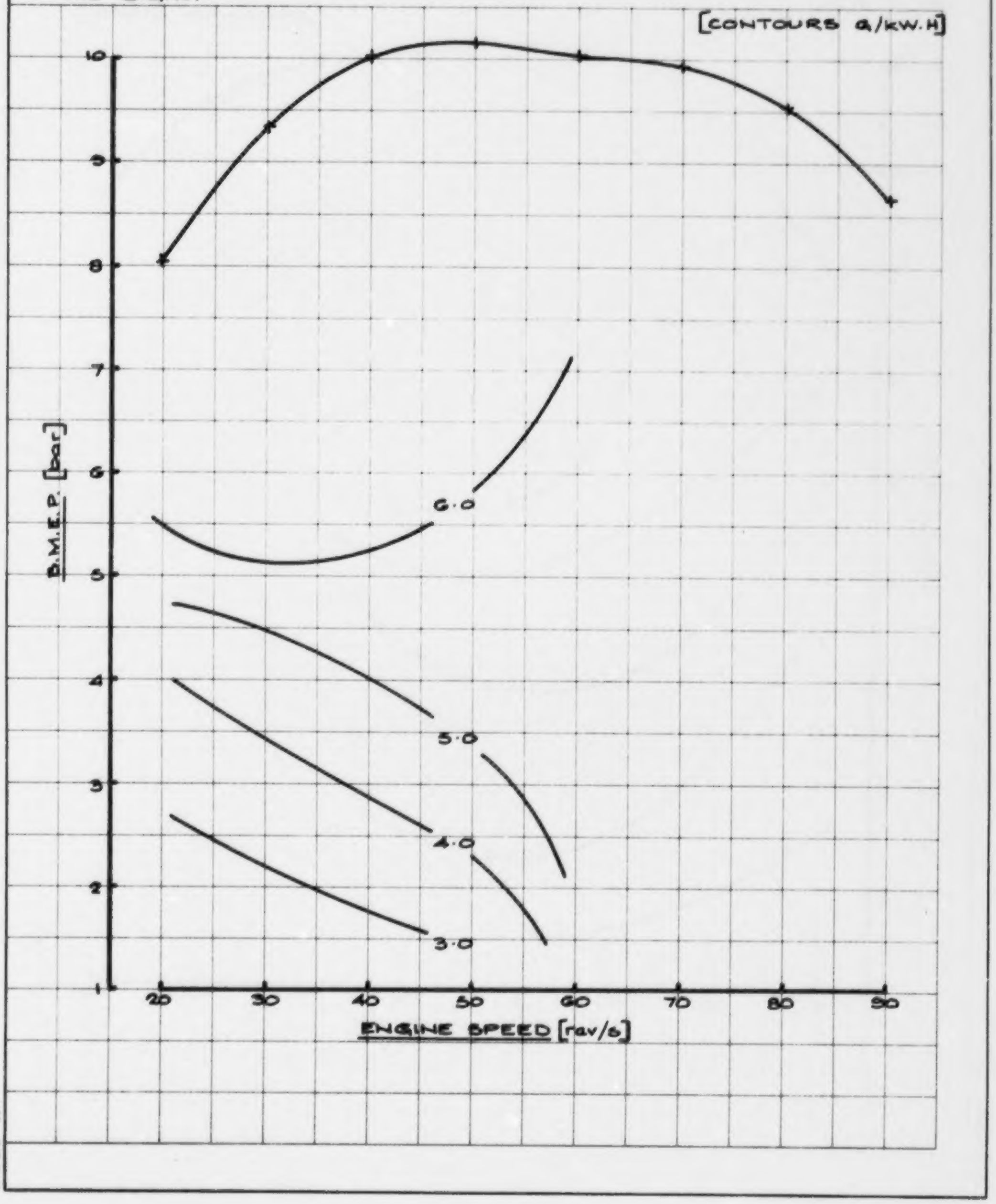
RICARDO

FIG. No. 49
Drg. No. D 50005
Date MARCH '83

EPA 1·5L HRCC ENGINE

NOx EMISSION CONTOURS

EQUIVALENCE RATIO ∼ 0·8 OPTIMUM IGNITION TIMINGS.
NO E.G.R.



W M LTD 2317

C.R.M. /L.M.

RICARDO

FIG. No. 50

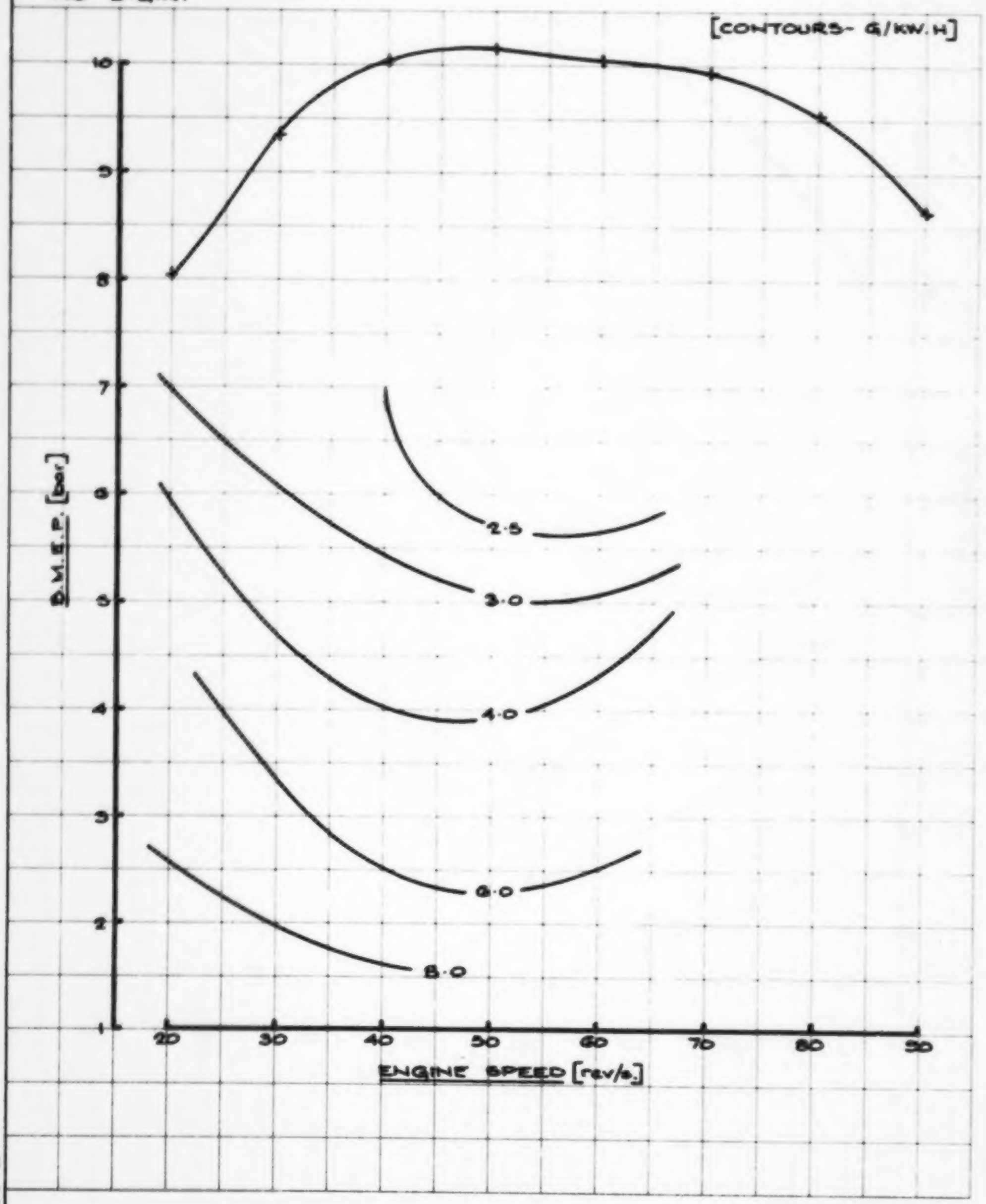
Drg. No. D50010

Date MARCH '83

EPA 1·5L HRCC ENGINE

HC EMISSION CONTOURS

EQUIVALENCE RATIO ~ 0·8 OPTIMUM IGNITION TIMINGS
NO E.G.R.



W M LTD 2317

C.R.M. /L.M.

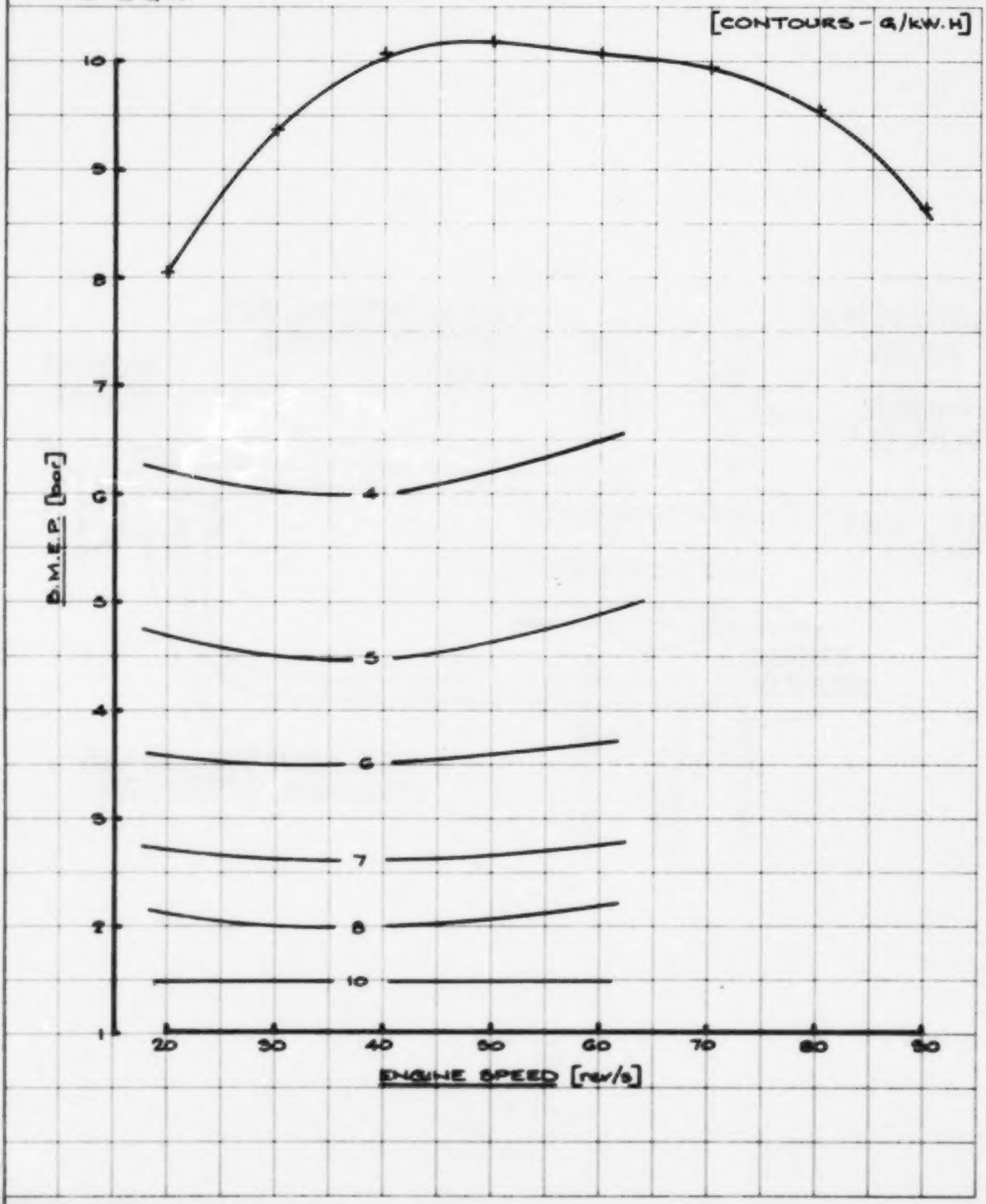
RICARDO

FIG. No. 81
Drg. No. D 50011
Date MARCH '83

EPA 1·5L HRCC ENGINE

CO EMISSION CONTOURS

EQUIVALENCE RATIO ~ 0·8 OPTIMUM IGNITION TIMINGS
NO E.G.R.



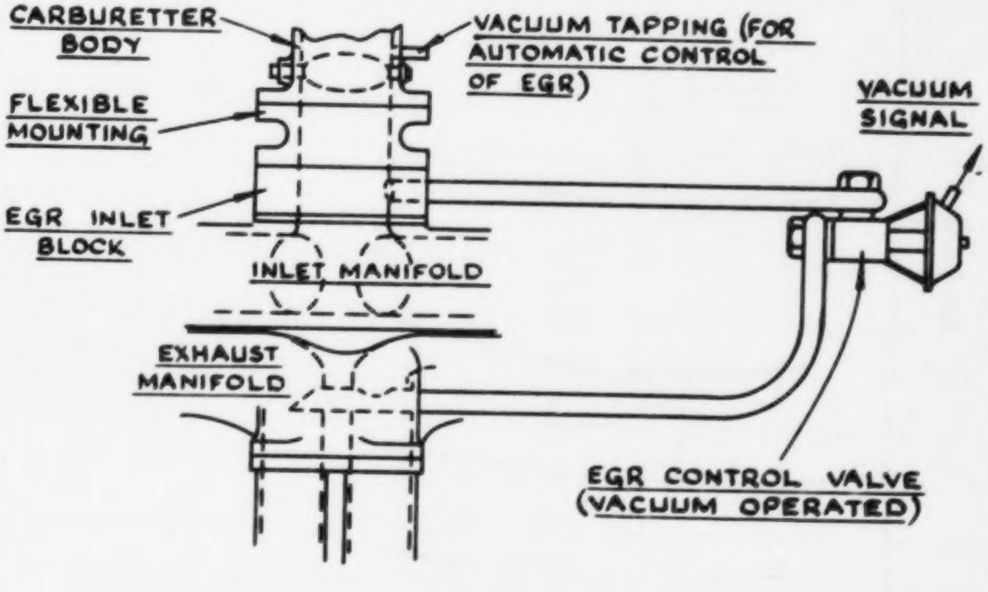
W M LTD 2317

/M.B.

RICARDO

FIG. No. 52
Drg. No. S9826
Date Feb '83

EPA 1·5ℓ HRCC ENGINE
EGR CIRCUIT



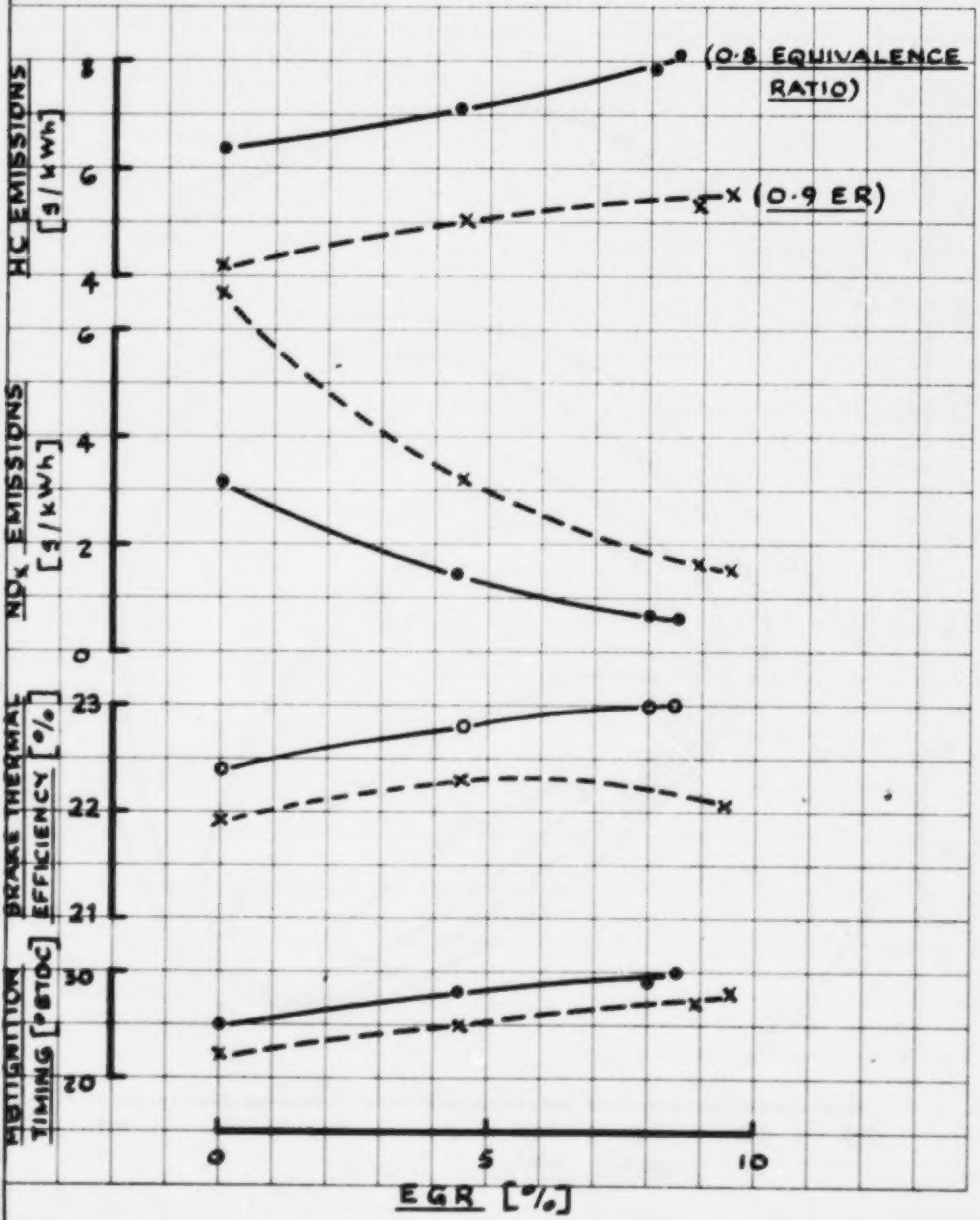
/M.B.

RICARDO

FIG. No. 53
Drg. No. D 50042
Date Feb '83

EPA 1·5ℓ HRCC ENGINE
EFFECT OF EGR AT 40 rev/s, 2·5 bar BMEP
METHANOL FUEL

[EGR PROBE AND EXHAUST BACKPRESSURE RESTRICTER INSTALLED FOR THIS AND SUBSEQUENT FIGURES]



IM.B.

RICARDO

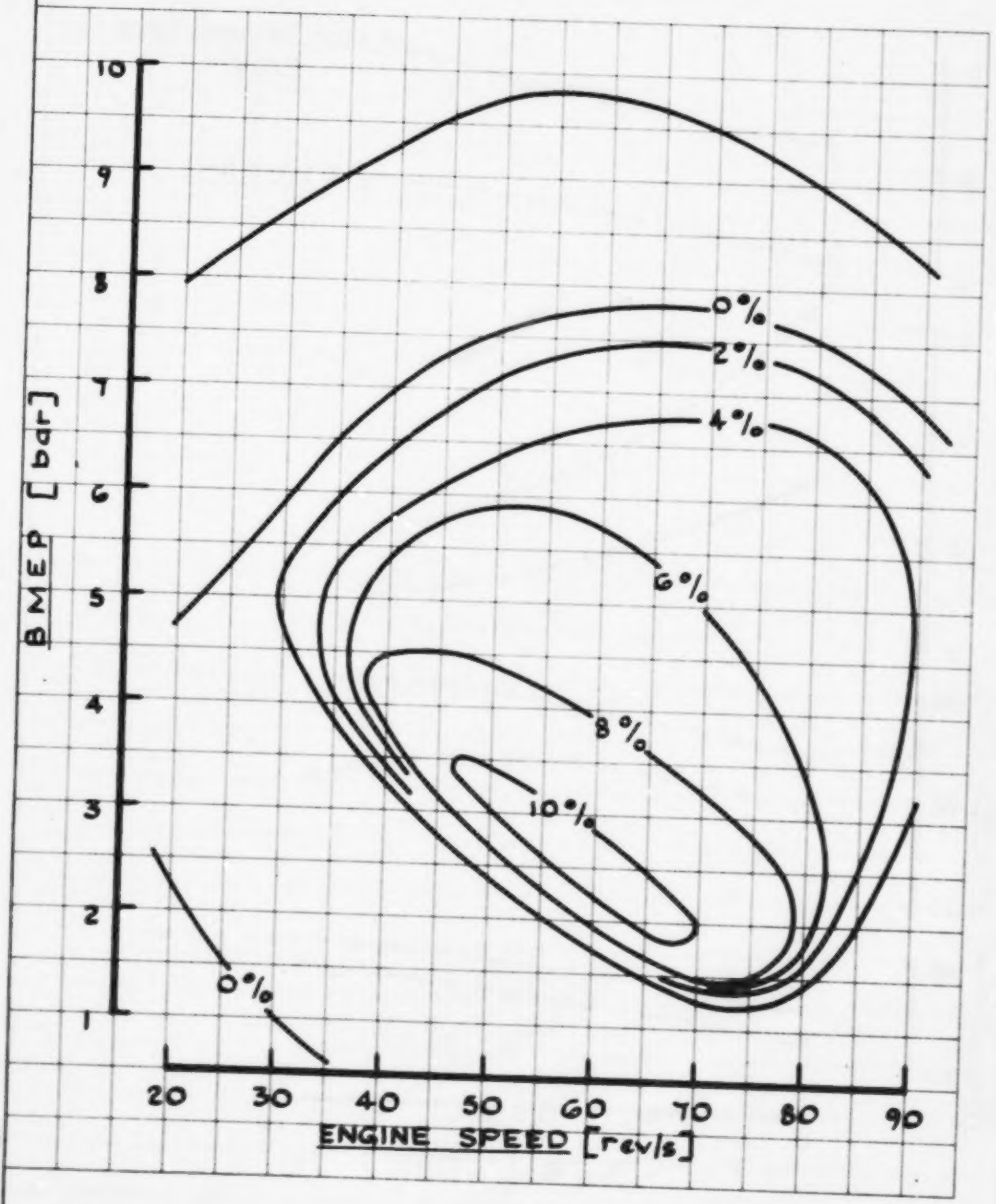
FIG. No. 54

Drg. No. D50043

Date Feb '83

EPA 1·5ℓ HRCC ENGINE

AUTOMATIC EGR SCHEDULE



IM.B.

RICARDO

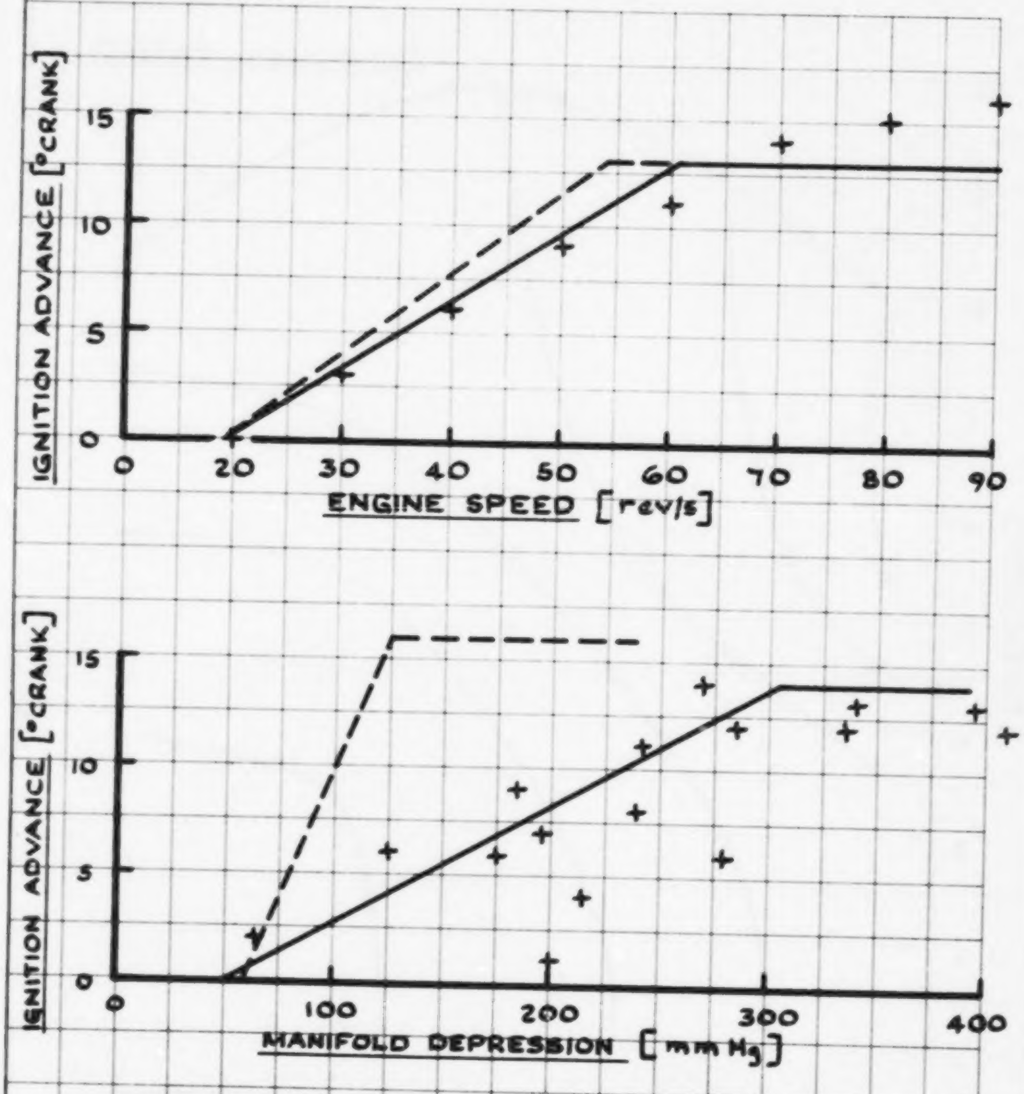
FIG. No. 55

Drg. No. D 50044

Date Feb '83

EPA 1·5ℓ HRCC ENGINE
DISTRIBUTOR CHARACTERISTICS

- - - - 'AS RECEIVED.'
—— AFTER MODIFICATION.
+ MBT TIMINGS.



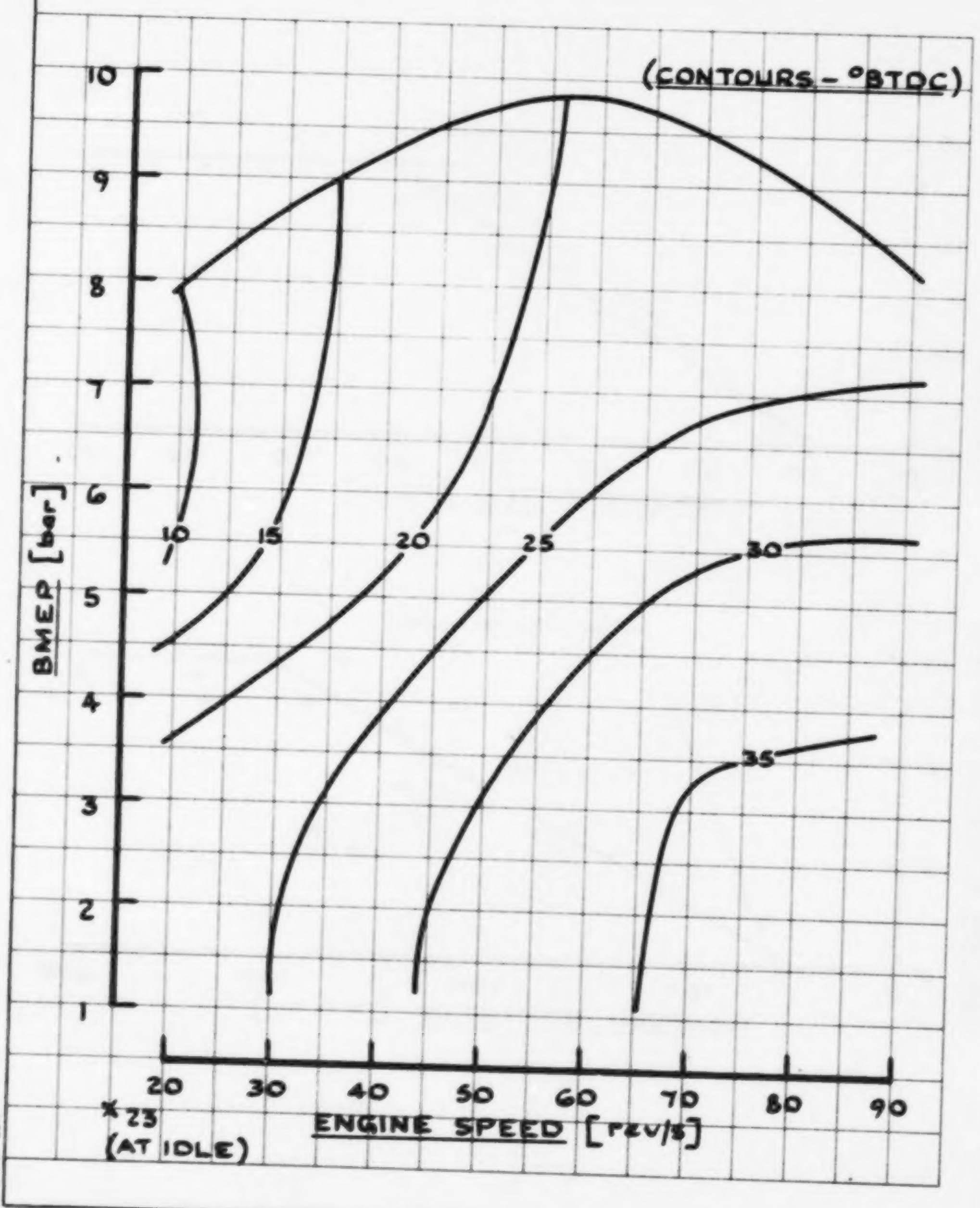
W M LTD 2317

/M.8.

RICARDO

FIG. No. 56
Drg. No. D 50045
Date Feb '83

EPA 1·5ℓ HRCC ENGINE
AUTOMATIC IGNITION TIMING SCHEDULE



W.M. LTD 2317

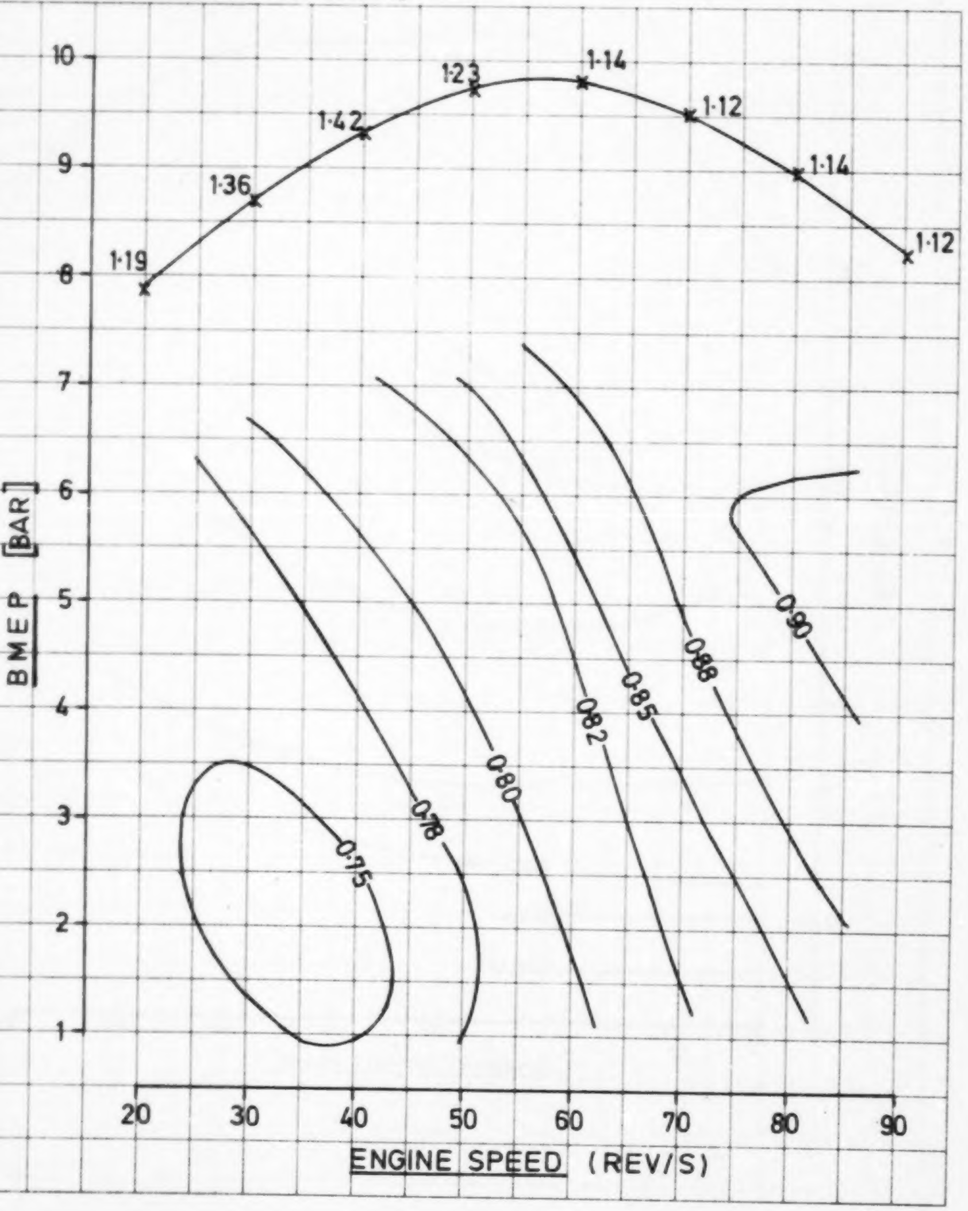
RICARDO

FIG. No. 57
Drg. No. D 50046
Date FEB 83

EPA 15L HRCC ENGINE
EQUIVALENCE RATIO CONTOURS WITH INITIAL AUTO CARBURETTOR SETTINGS

$$\text{(EQUIVALENCE RATIO} = \frac{\text{STOICHIOMETRIC AIR/FUEL}}{\text{ACTUAL AIR/FUEL}}\text{)}$$

(SUPPLEMENTARY FULL LOAD ENRICHMENT SYSTEM ADDED FOR THIS AND SUBSEQUENT FIGURES)



W M LTD 2317

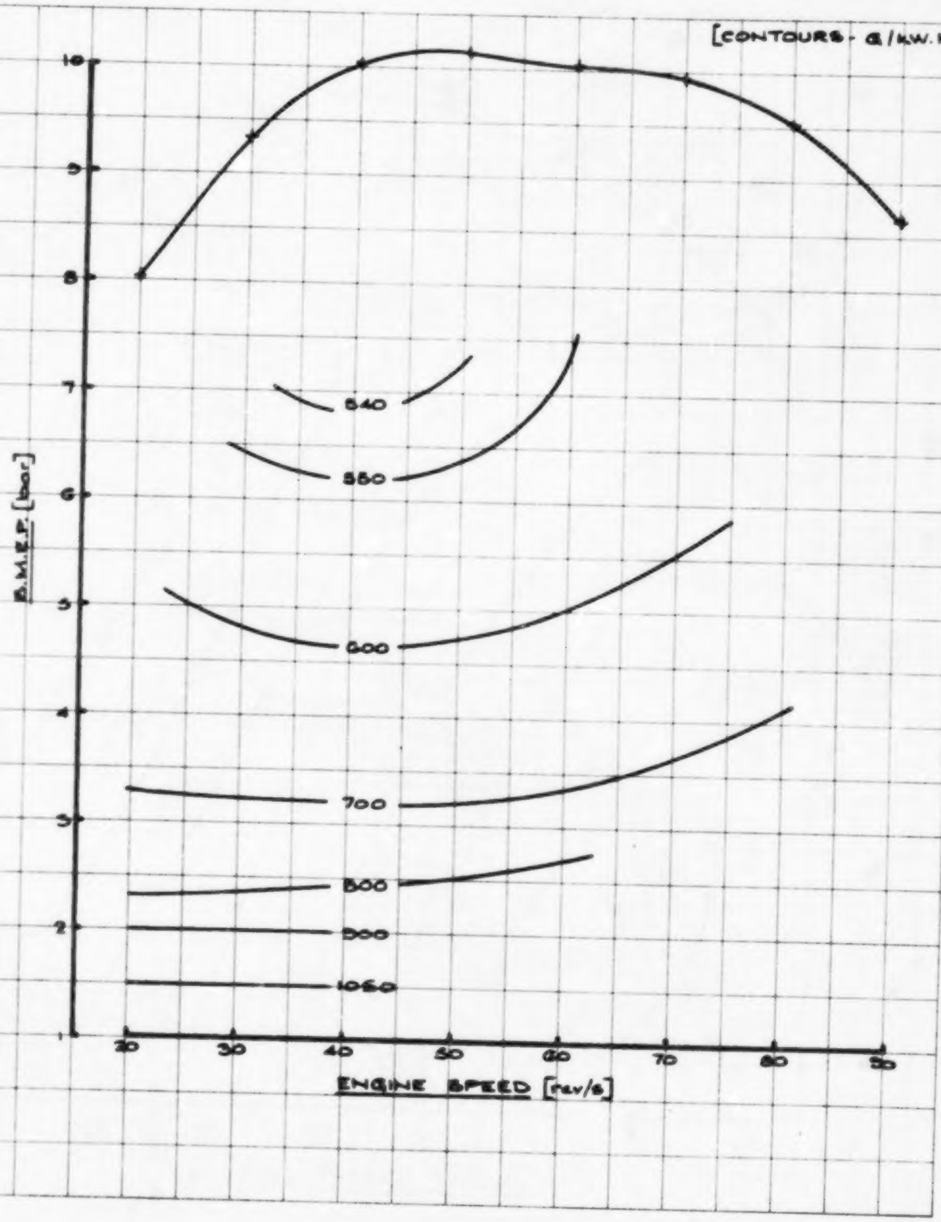
RICARDO

C.R.M. /L.M.
FIG. No. 58
Drg. No. D 50012
Date MARCH '83

EPA 1.5L HRCC ENGINE

B.S.F.C. CONTOURS

[AUTO FUELLING [LEAN], AUTO IGNITION, AUTO E.G.R]



W M LTD 2317

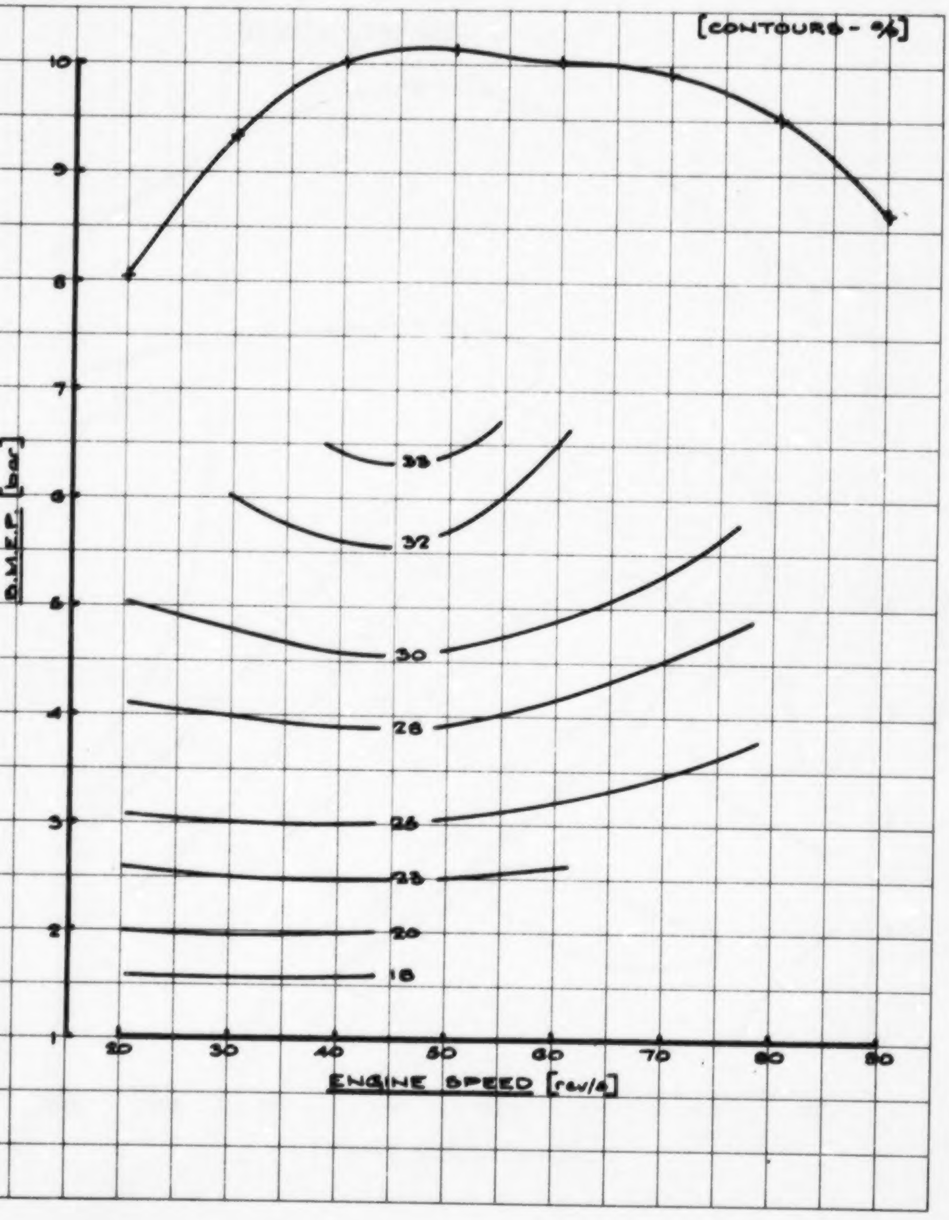
RICARDO

C.R.M./L.M.
FIG. No. 59
Drg. No. D 50613
Date MARCH '83

EPA 1.5L HRCC ENGINE

BRAKE THERMAL EFFICIENCY CONTOURS

[AUTO FUELLING [LEAN], AUTO IGNITION, AUTO E.G.R.]



W M LTD 2317

RICARDO

CRM/TW

FIG. No. 60

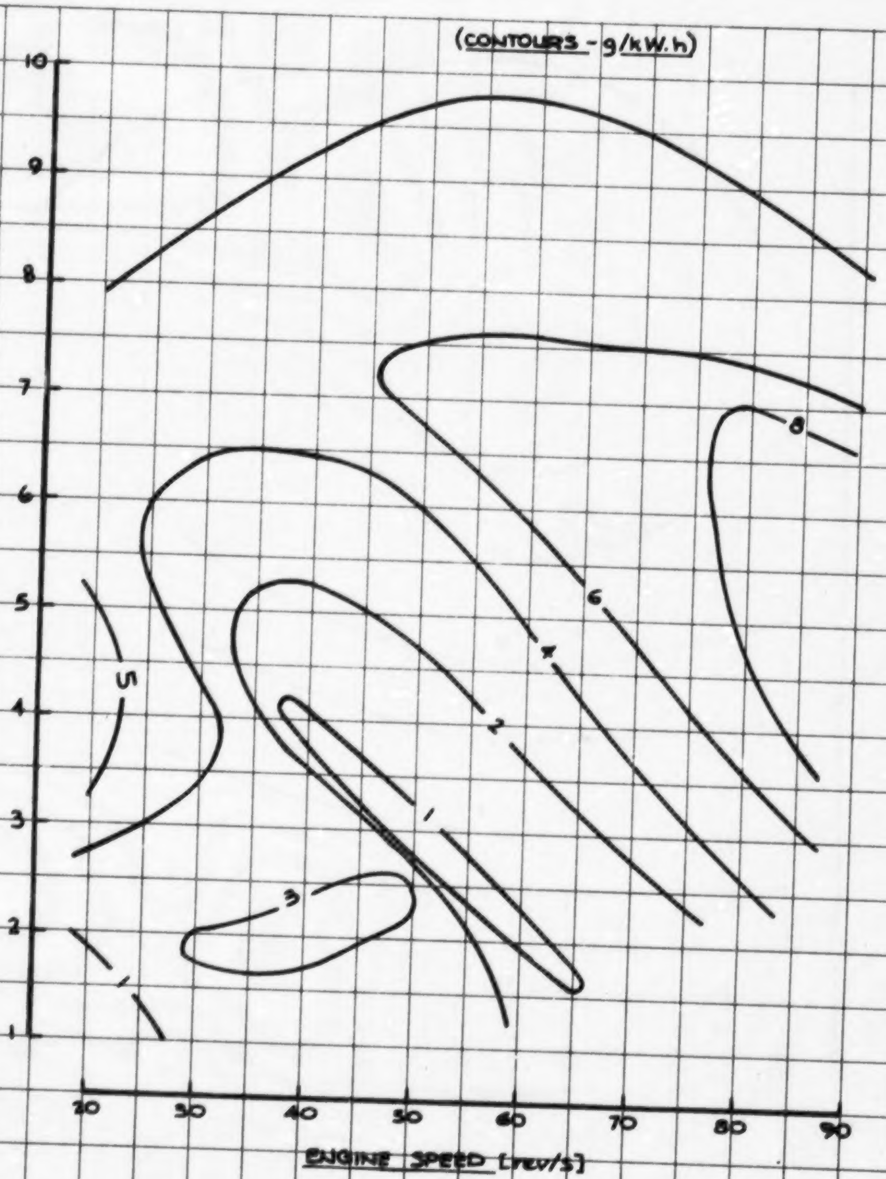
Drg. No. D49887

Date FEB '85

EPA 1·5 L HRCC ENGINE

NOx EMISSION CONTOURS

(AUTO FUELLING (LEAN), AUTO IGNITION, AUTO EGR)



W M LTD 2317

RICARDO

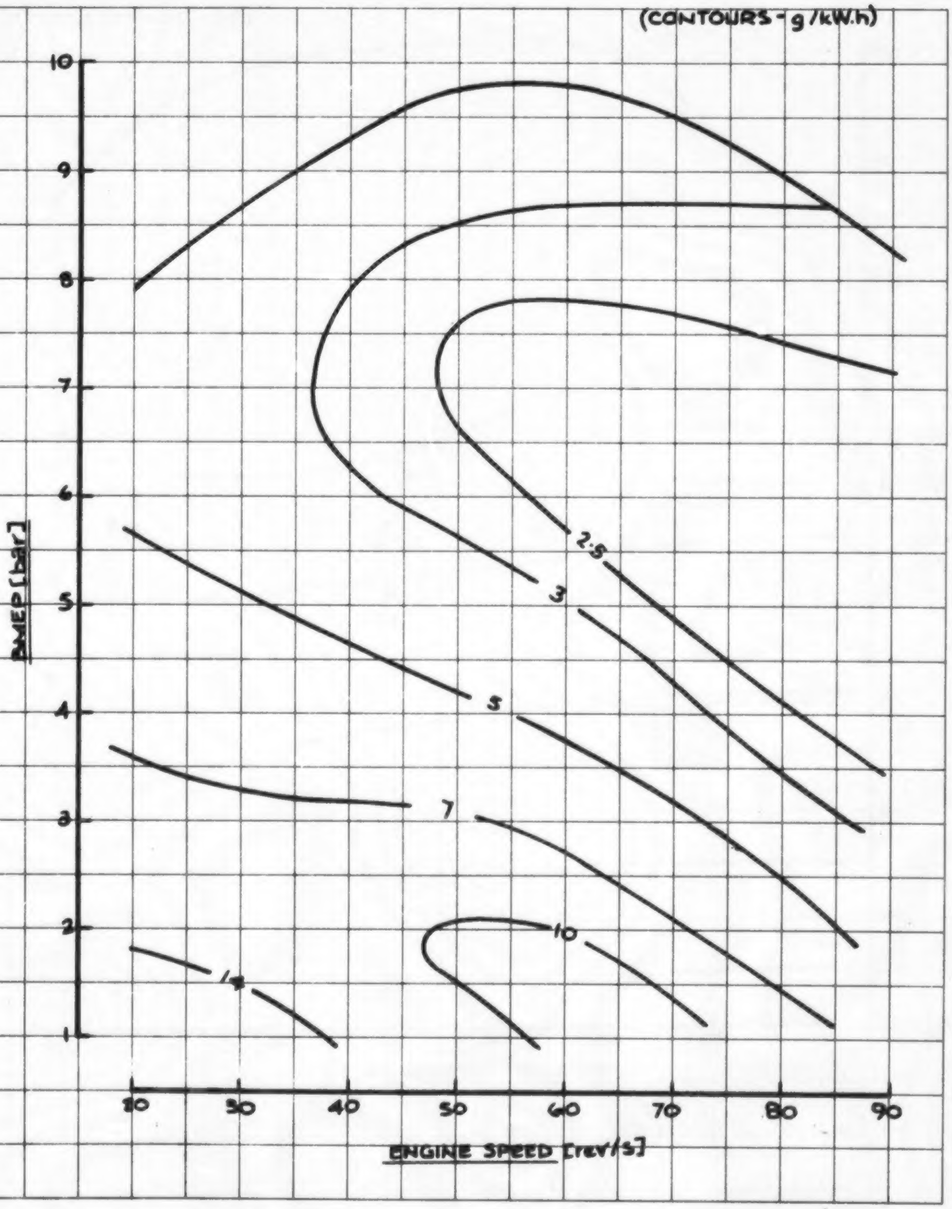
CRM/TW

FIG. No. 61

Drg. No. D49886

Date FEB '83

EPA 1.5L HRCC ENGINE
HC EMISSION CONTOURS
(AUTO FUELLING (LEAN), AUTO IGNITION, AUTO EGR)



W M LTD 2317

C.R.M. / L.M.

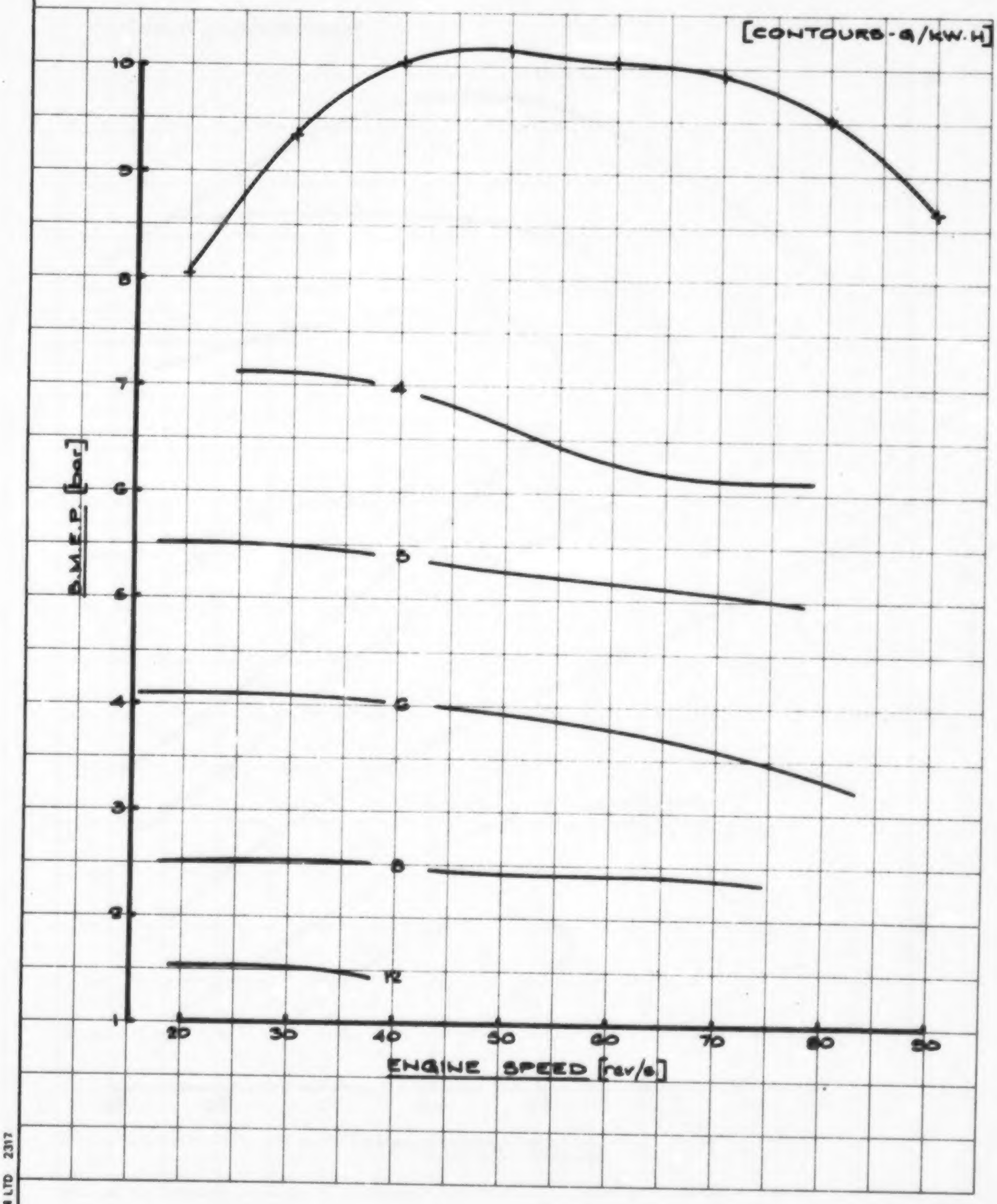
RICARDO

FIG. No. 62
Drg. No. 80014
Date MARCH '83

EPA 1·5L HRCC ENGINE

CO EMISSION CONTOURS

[AUTO FUELLING [LEAN], AUTO IGNITION, AUTO E.G.R.]



C.R.M./L.M.

RICARDO

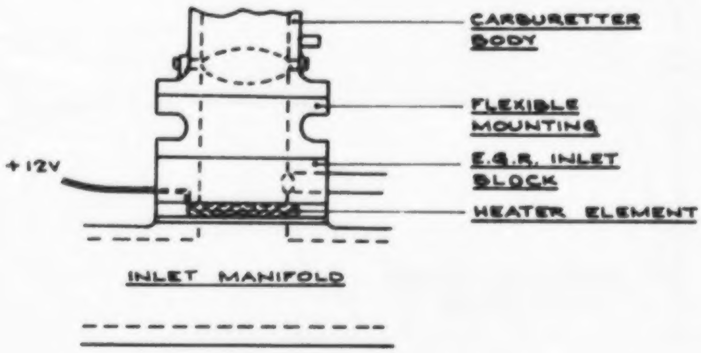
FIG. No. 63

Drg. No. S. 5804

Date MARCH '86

EPA 1·5L HRCC ENGINE

INSTALLATION OF INLET HEATER GRID



JPM LTD.
6448MT

1M.B.

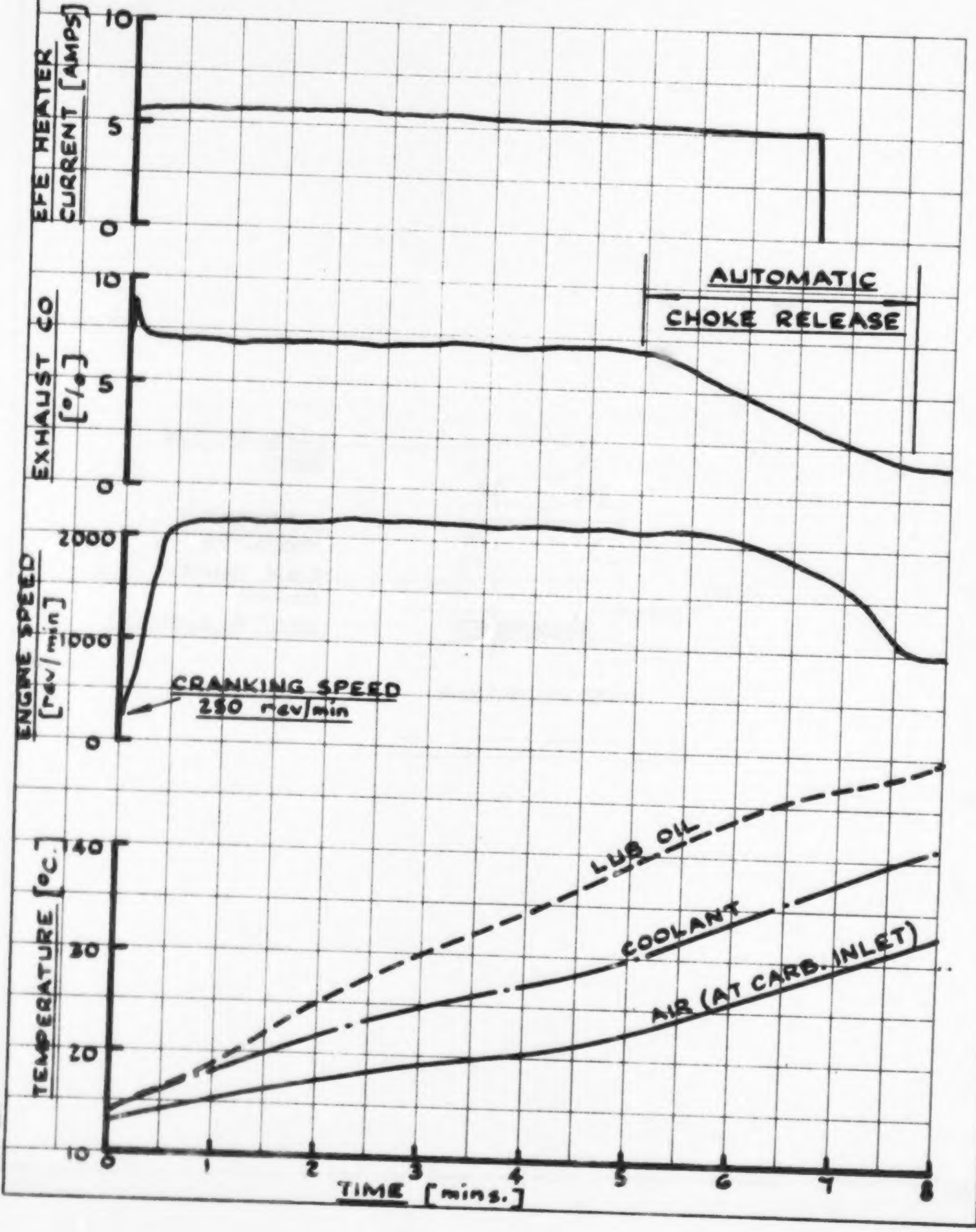
RICARDO

FIG. No. 64
Drg. No. D 50047
Date Feb '83

EPA 1·5ℓ HRCC ENGINE

TEST-BED STARTING CHARACTERISTICS WITH METHANOL FUEL.

(HEATER GRID UNDER CARBURETTOR AND AIR CLEANER INSTALLED FOR THIS AND SUBSEQUENT FIGURES)

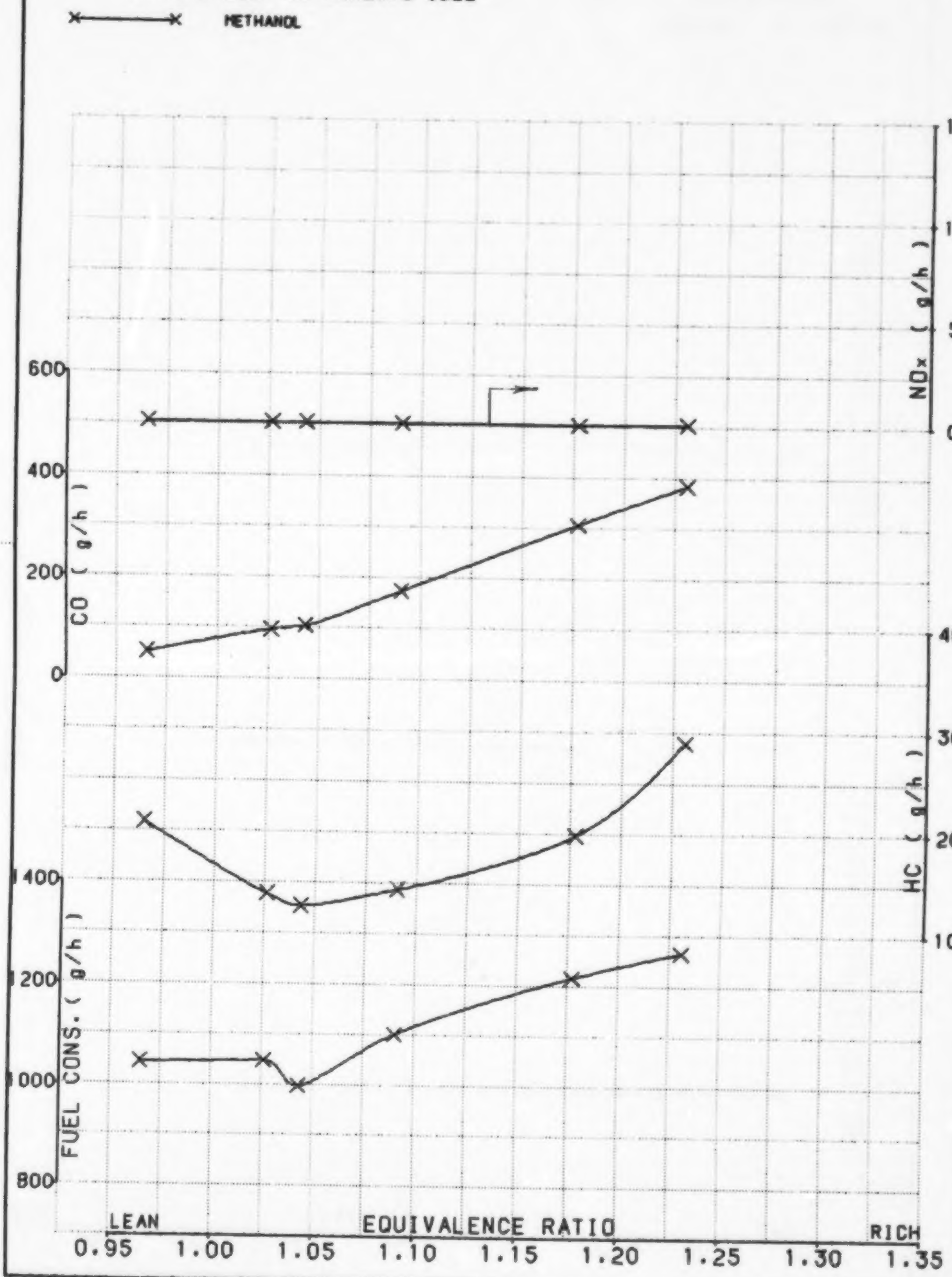


W H LTD 2317

RICARDO

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP AT 15REV/S IDLE

Fig.No. 65
Drg.No.
Date: 28 Jan 1983



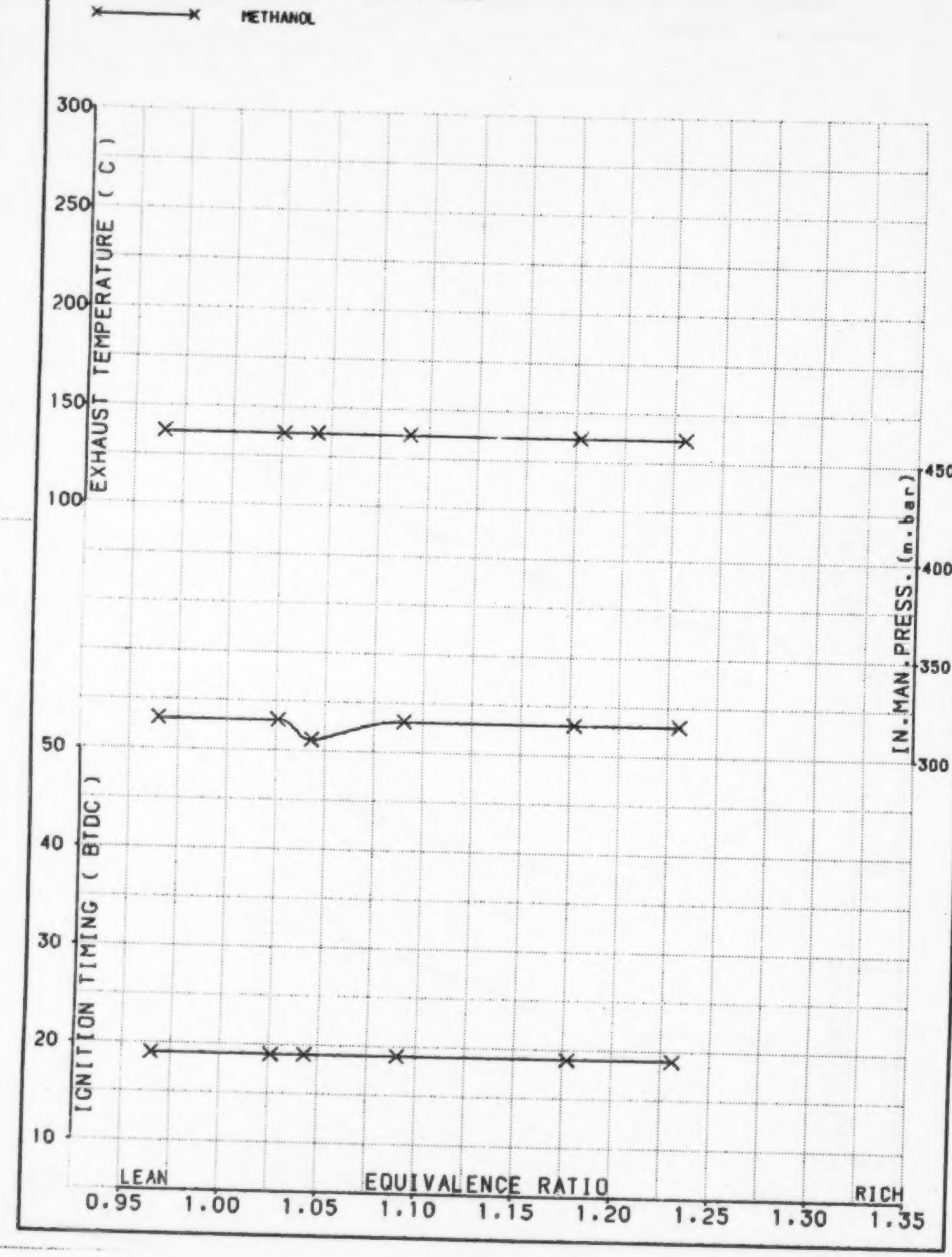
RICARDO

Fig.No. 66

Drg.No.

Date: 28 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP AT 15REV/S IDLE



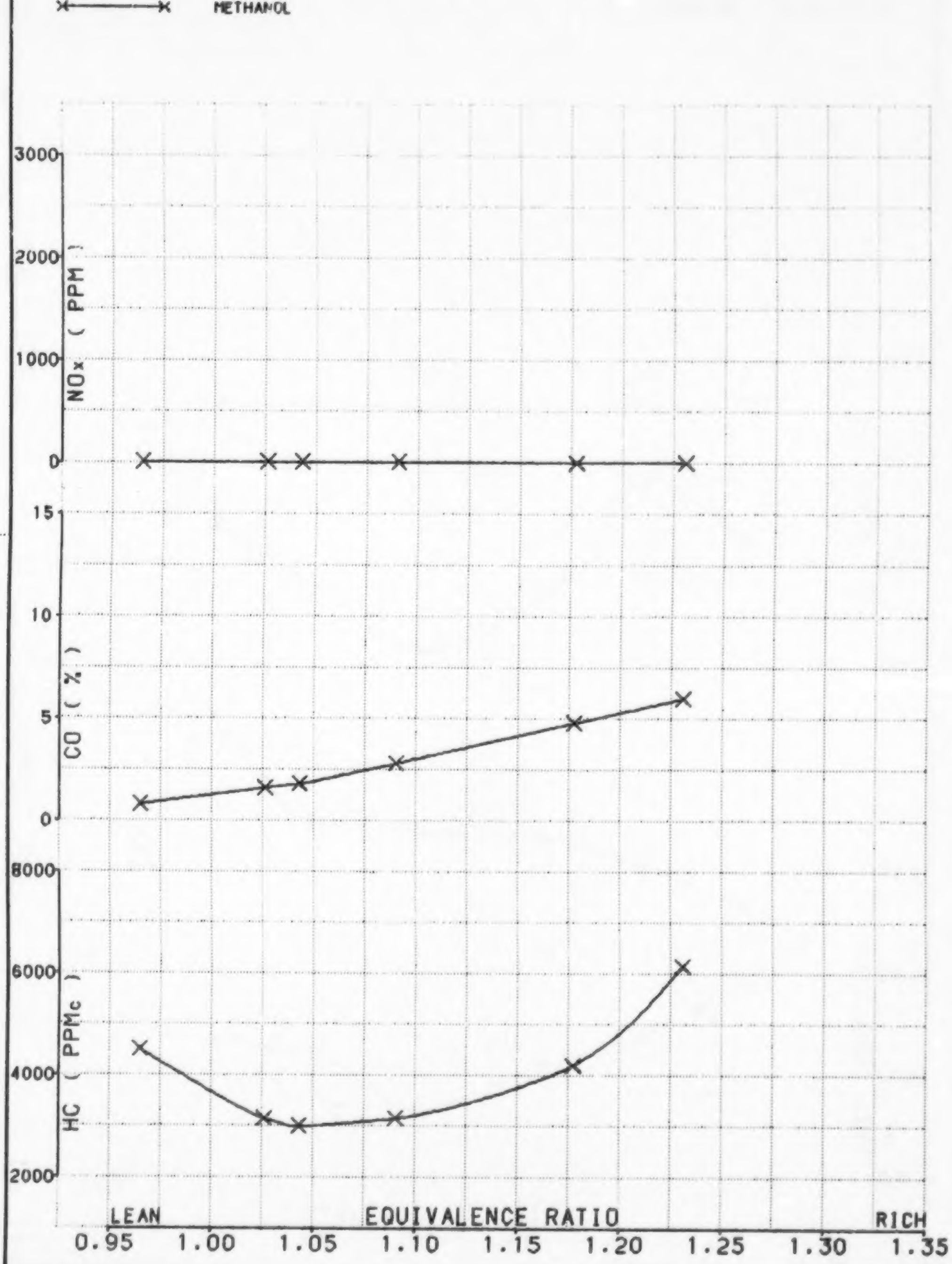
RICARDO

Fig.No. 67

Drg.No.

Date: 28 Jan 1983

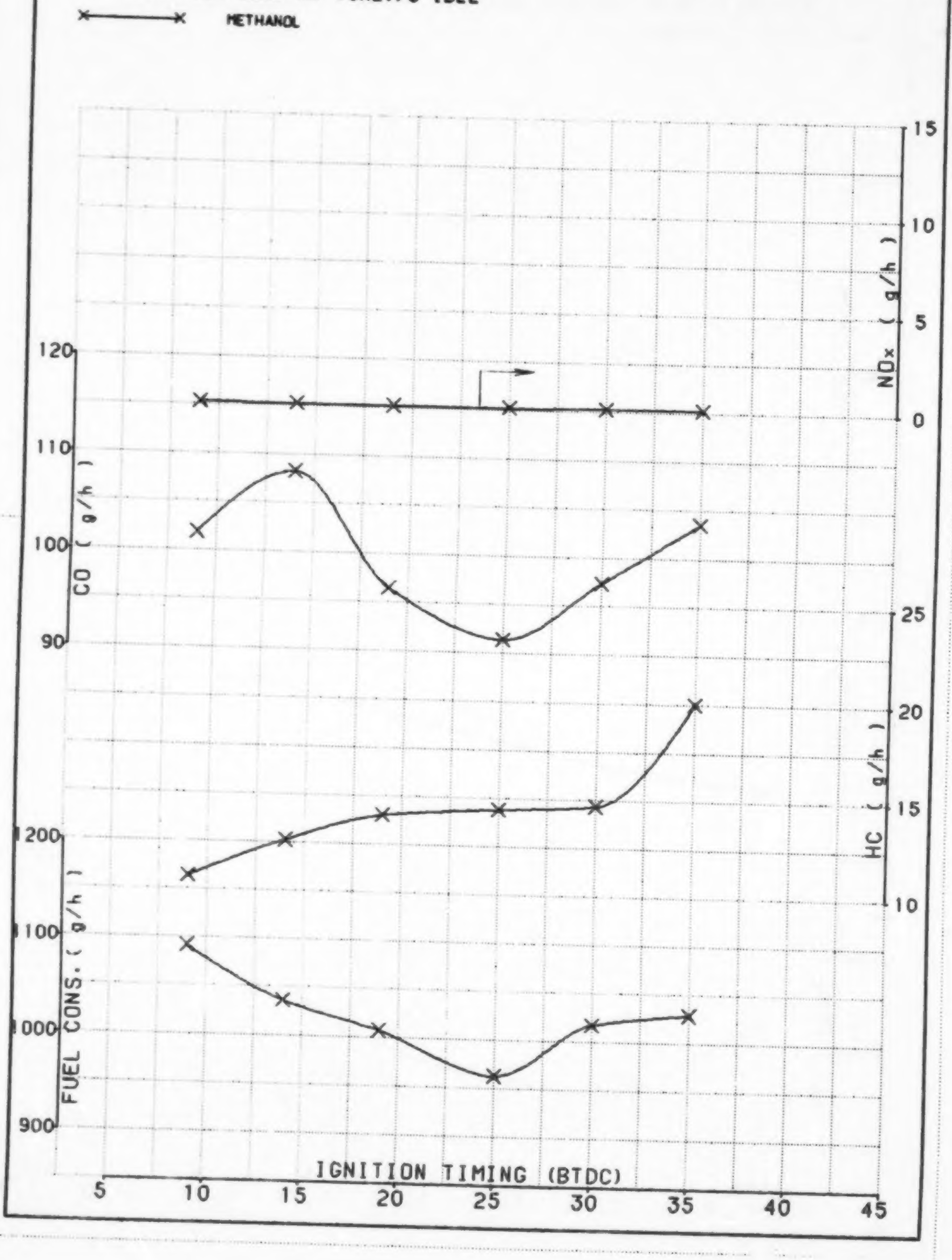
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
MIXTURE LOOP AT 15REV/S IDLE



RICARDO

Fig.No. 68
Drg.No.
Date: 28 Jan 1983

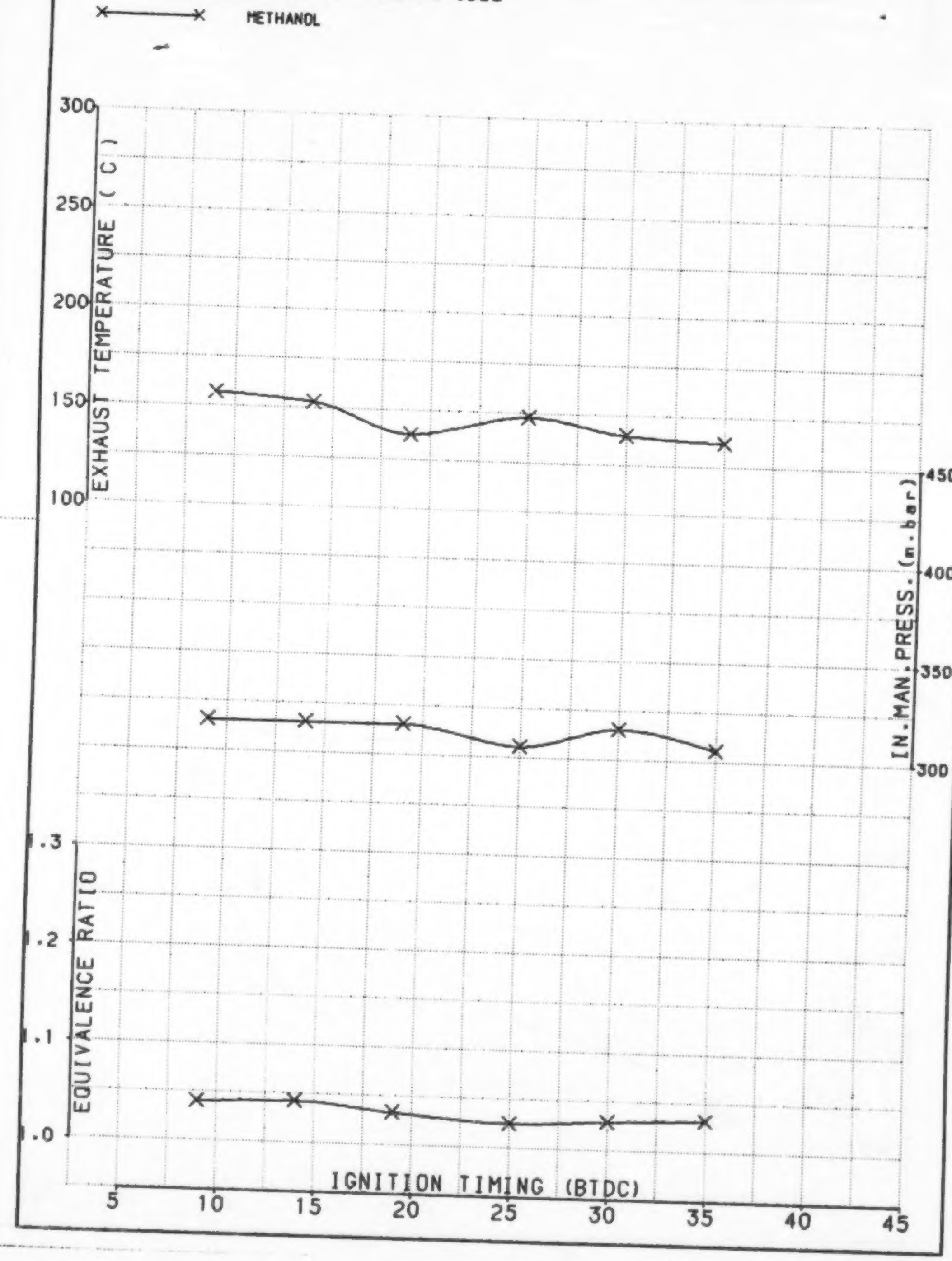
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
IGNITION LOOP AT 15REV/S IDLE



RICARDO

Fig.No. 69
Drg.No.
Date: 28 Jan 1983

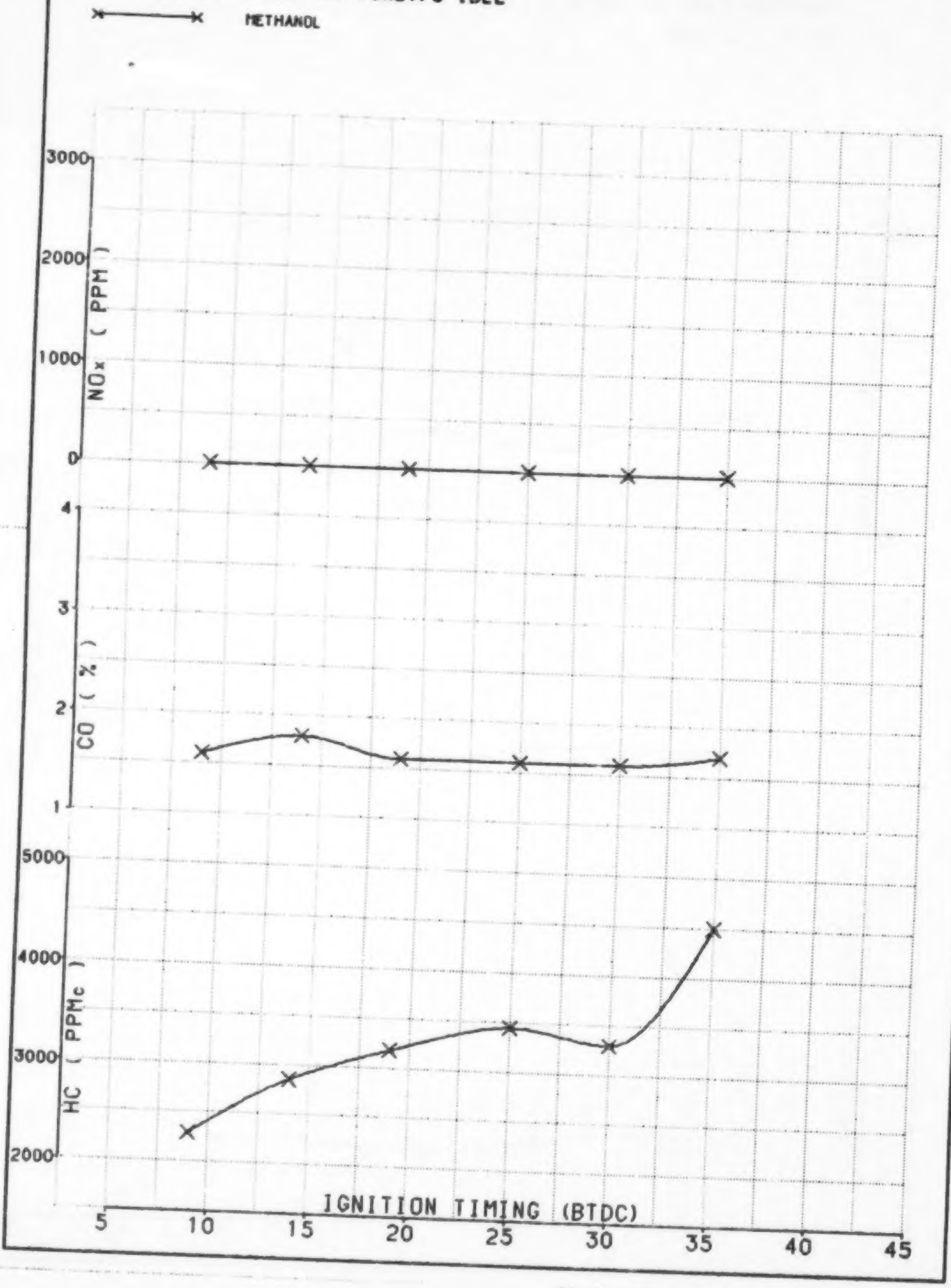
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
IGNITION LOOP AT 15REV/S IDLE



RICARDO

Fig.No. 70
Drg.No.
Date: 28 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
IGNITION LOOP AT 15REV/S IDLE



S.B./M.B.

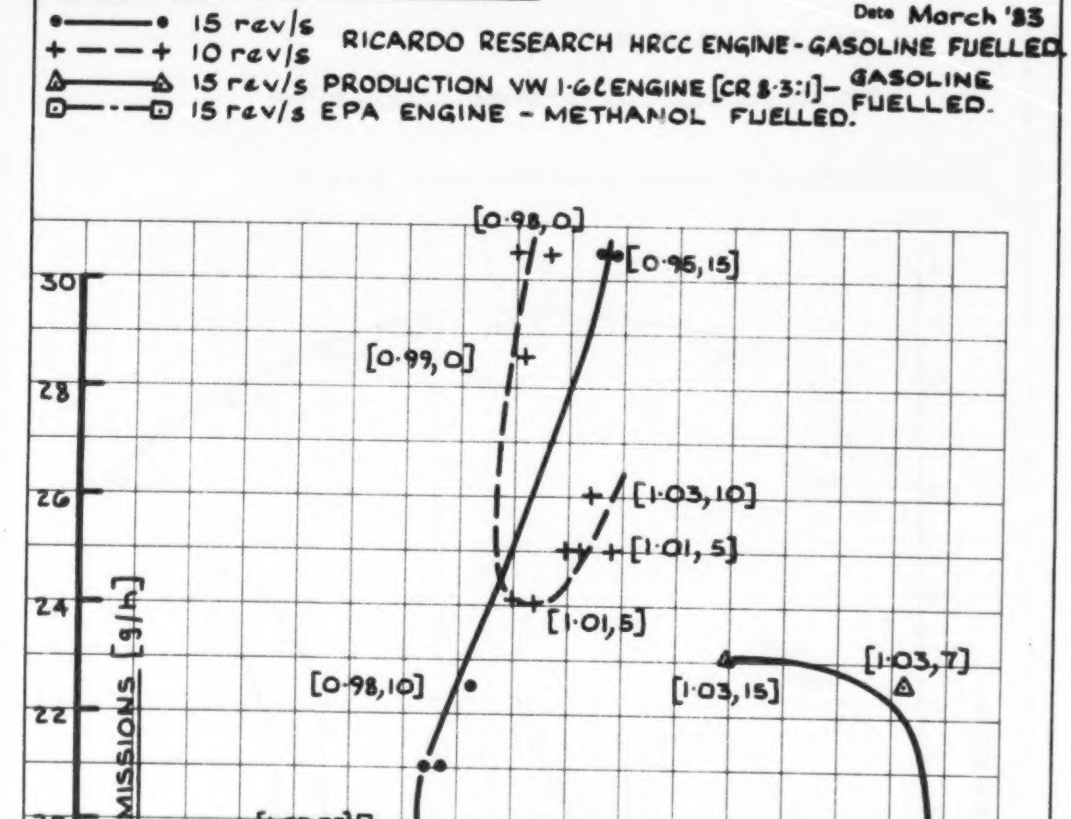
RICARDO

FIG. No. 71

Drg. No. D

Date March '83

EPA 1·5ℓ HRCC ENGINE



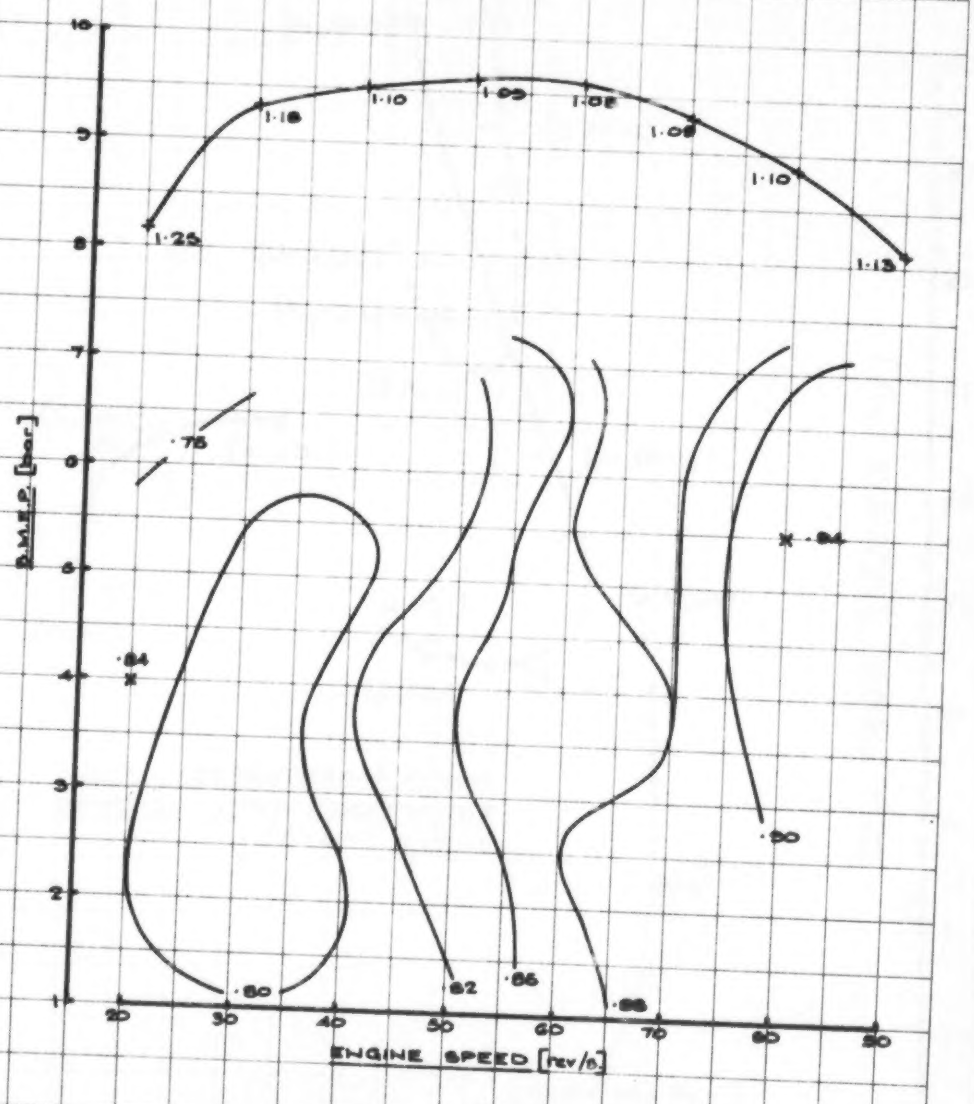
RICARDO

C.R.M./L.M.
FIG. No. 72
Drg. No. D 60016
Date MARCH '83

EPA 1·6L HRCC ENGINE

EQUIVALENCE RATIO CONTOURS – FINAL BUILD

[AUTO FUELLING, AUTO IGNITION, AUTO E.G.R.]



W M LTD 2317

RICARDO

Fig.No. 73

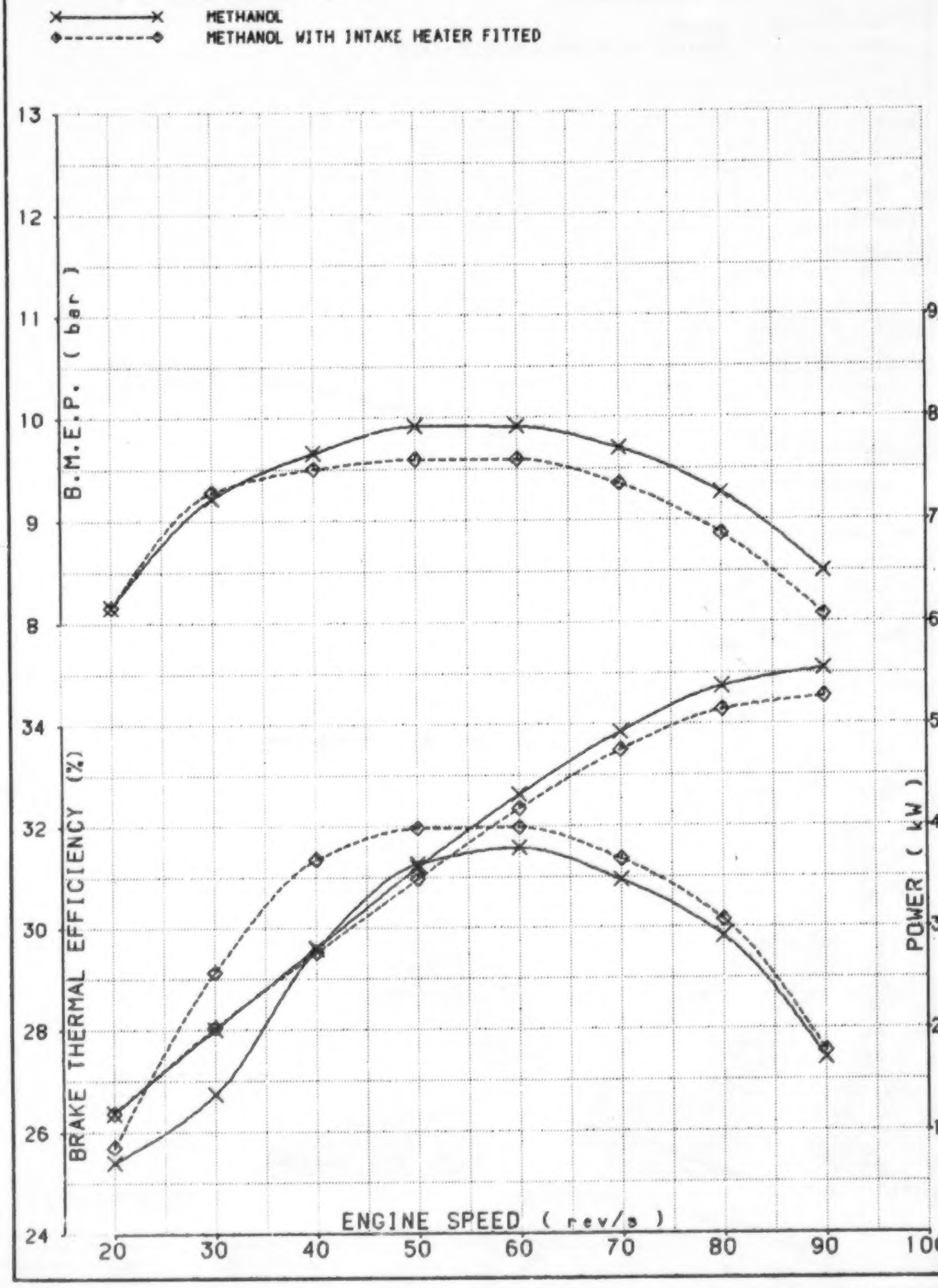
Drg.No.

Date: 12 Jan 1983

EPA 1.5L HRCC ENGINE

13:1CR (79.5 X 73)

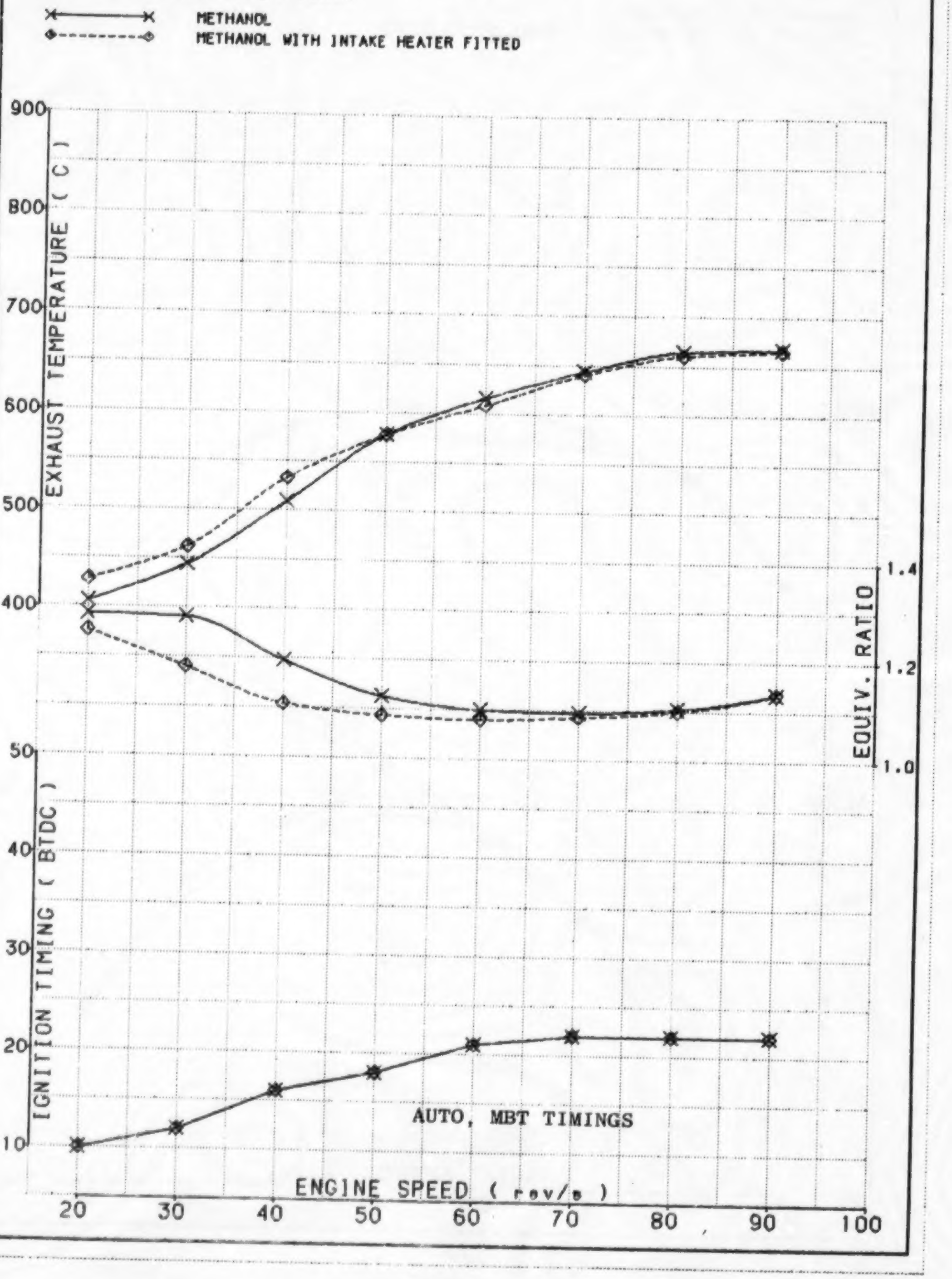
FULL LOAD POWER CURVE



RICARDO

Fig.No. 74
Drg.No.
Date: 12 Jan 1983

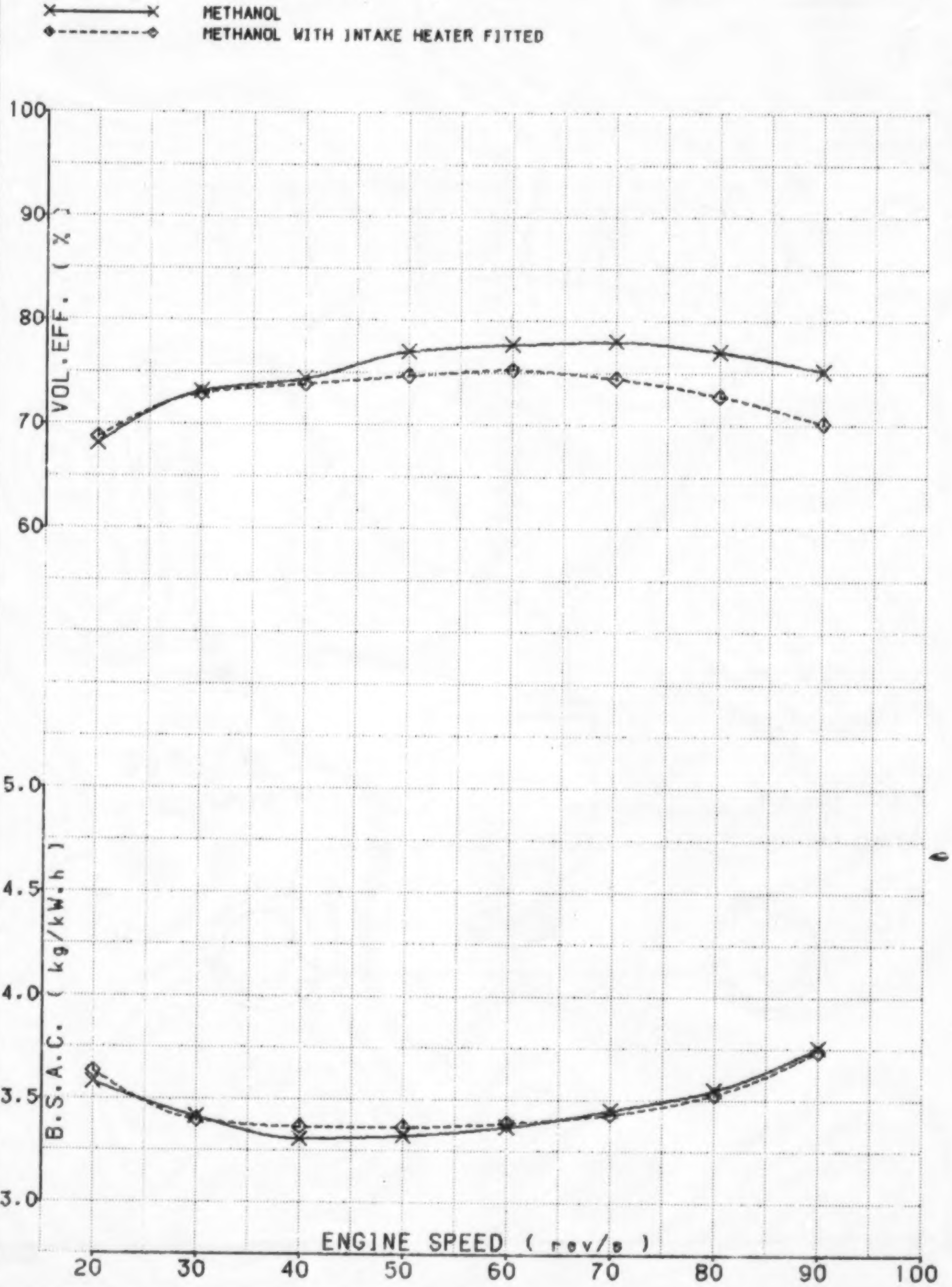
EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
FULL LOAD POWER CURVE



RICARDO

Fig.No. 75
Drg.No.
Date: 12 Jan 1983

EPA 1.5L HRCC ENGINE
13:1CR (79.5 X 73)
FULL LOAD POWER CURVE

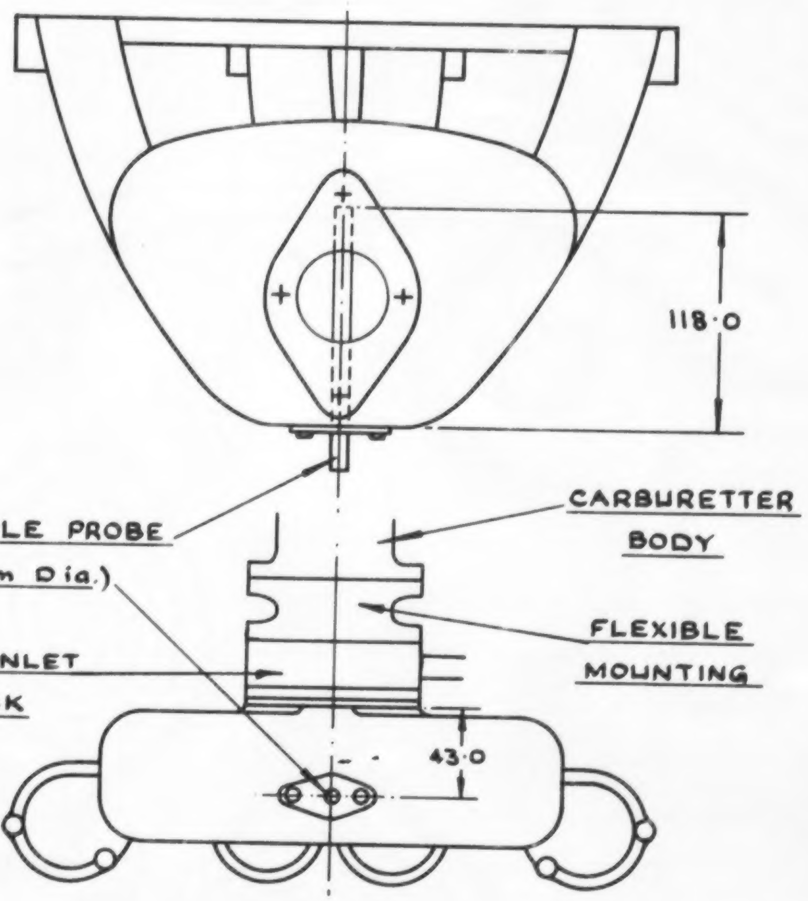


1M.B.

RICARDO

FIG. No. 76
Drg. No. S9827
Date Feb '83

EPA 1·5ℓ HRCC ENGINE
POSITION OF INLET MANFOLD SAMPLE PROBE.



JPM LTD.

6448MT

C.R.M. / L.M.

RICARDO

FIG. No. 11

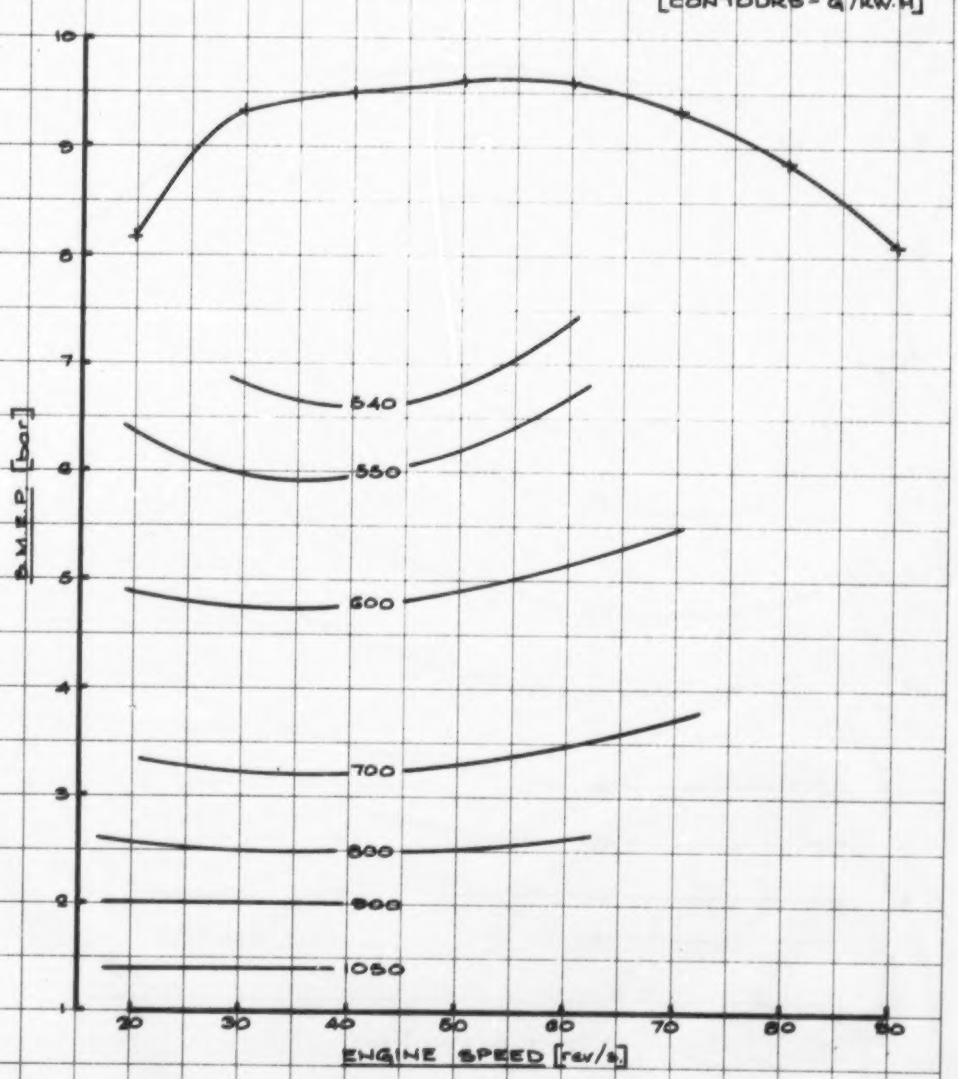
Drg. No. D50016

Date MARCH '85

EPA 1.6L HRCC ENGINE

B.S.F.C. CONTOURS - FINAL BUILD

[AUTO FUELLING, AUTO IGNITION, AUTO E.G.R.]



W M LTD 2317

C.R.M. / L.M.

RICARDO

FIG. No. 78

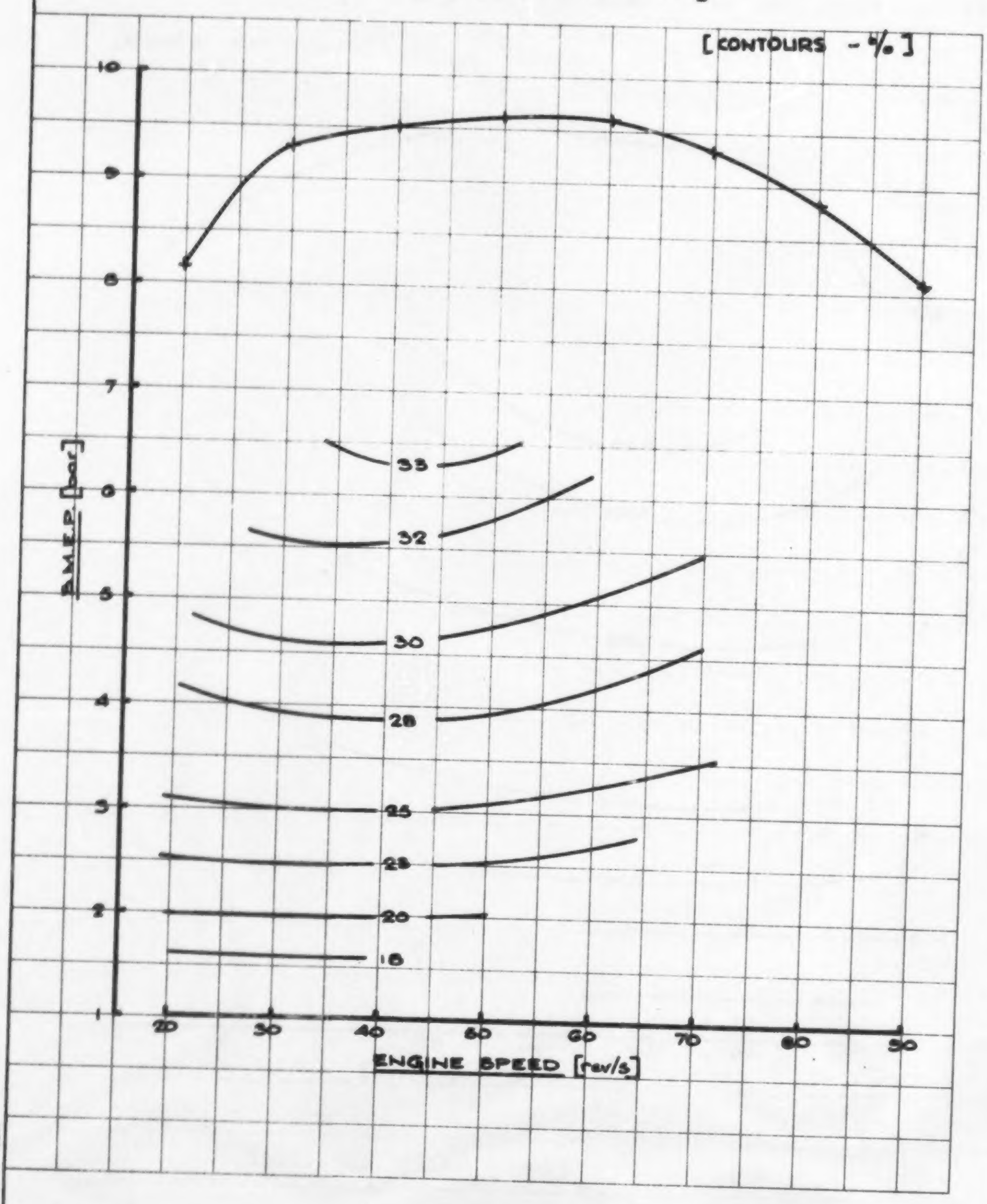
Drg. No. D 50017

Date MARCH '83

EPA 1·5L HRCC ENGINE

BRAKE THERMAL EFFICIENCY CONTOURS – FINAL BUILD

[AUTO FUELLING, AUTO IGNITION, AUTO E.G.R.]



C.R.M./L.M.

RICARDO

FIG. No. 79

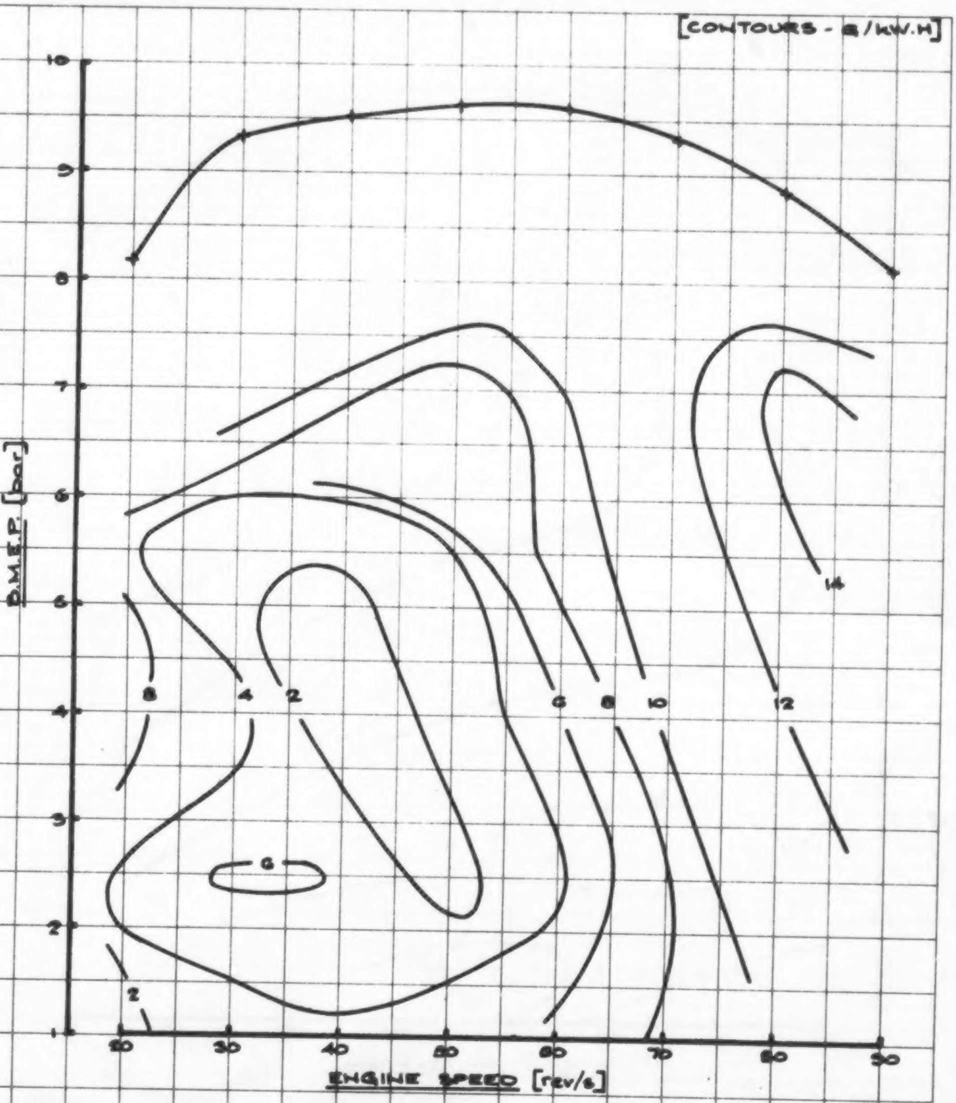
Drg. No. D 60018

Date MARCH '83

EPA 1·5L HRCC ENGINE

NOx EMISSION CONTOURS – FINAL BUILD

[AUTO FUELLING, AUTO IGNITION, AUTO E.G.R.]



W M LTD 2317

RICARDO

C.R.M. /L.M

FIG. No. 80

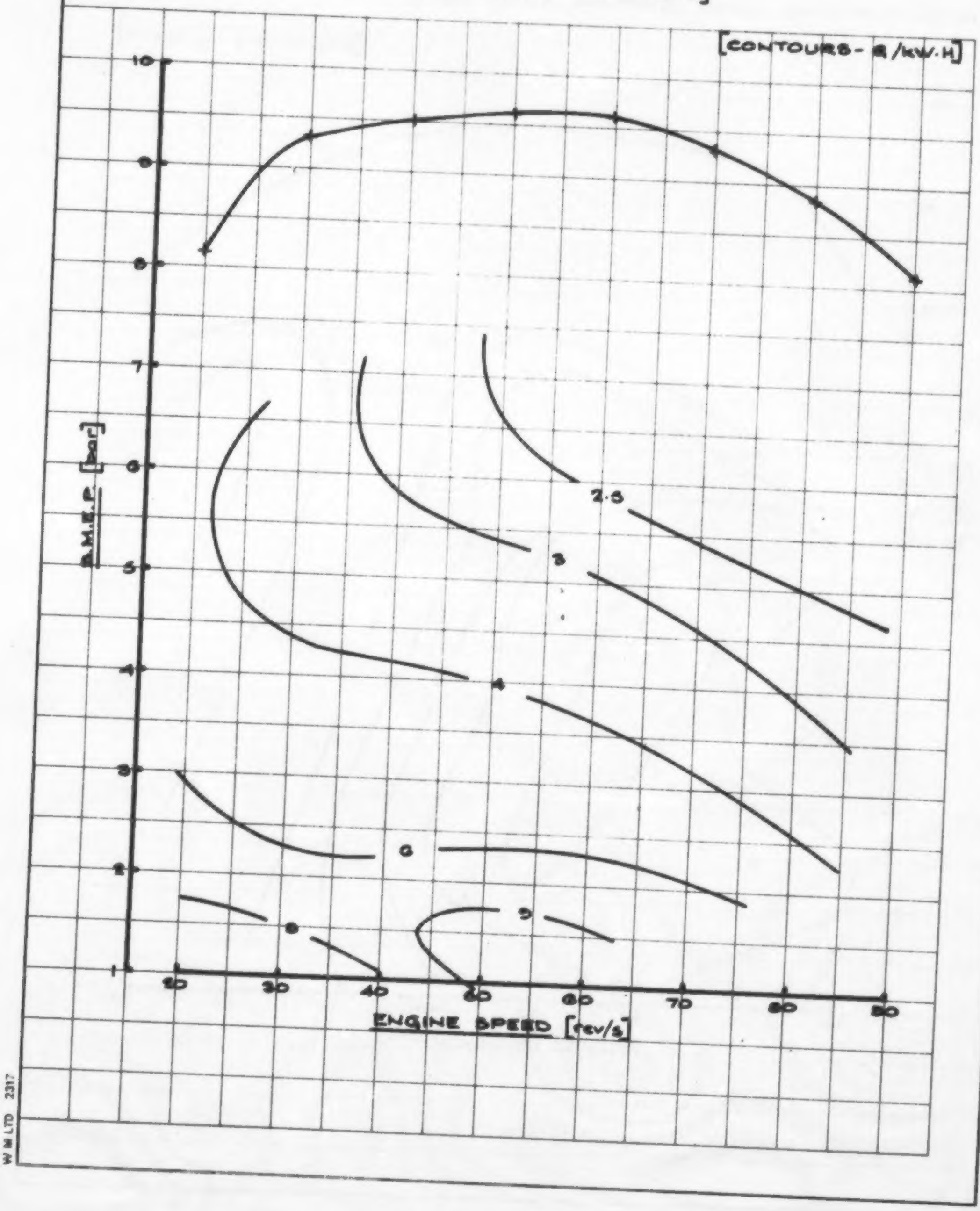
Drg. No. D 5001D

Date MARCH '85

EPA 1·5L HRCC ENGINE

HC EMISSION CONTOURS - FINAL BUILD

[AUTO FUELLING, AUTO IGNITION, AUTO E.G.R.]



W M LTD 2317

C.R.M. /L.M.

RICARDO

FIG. No. 81

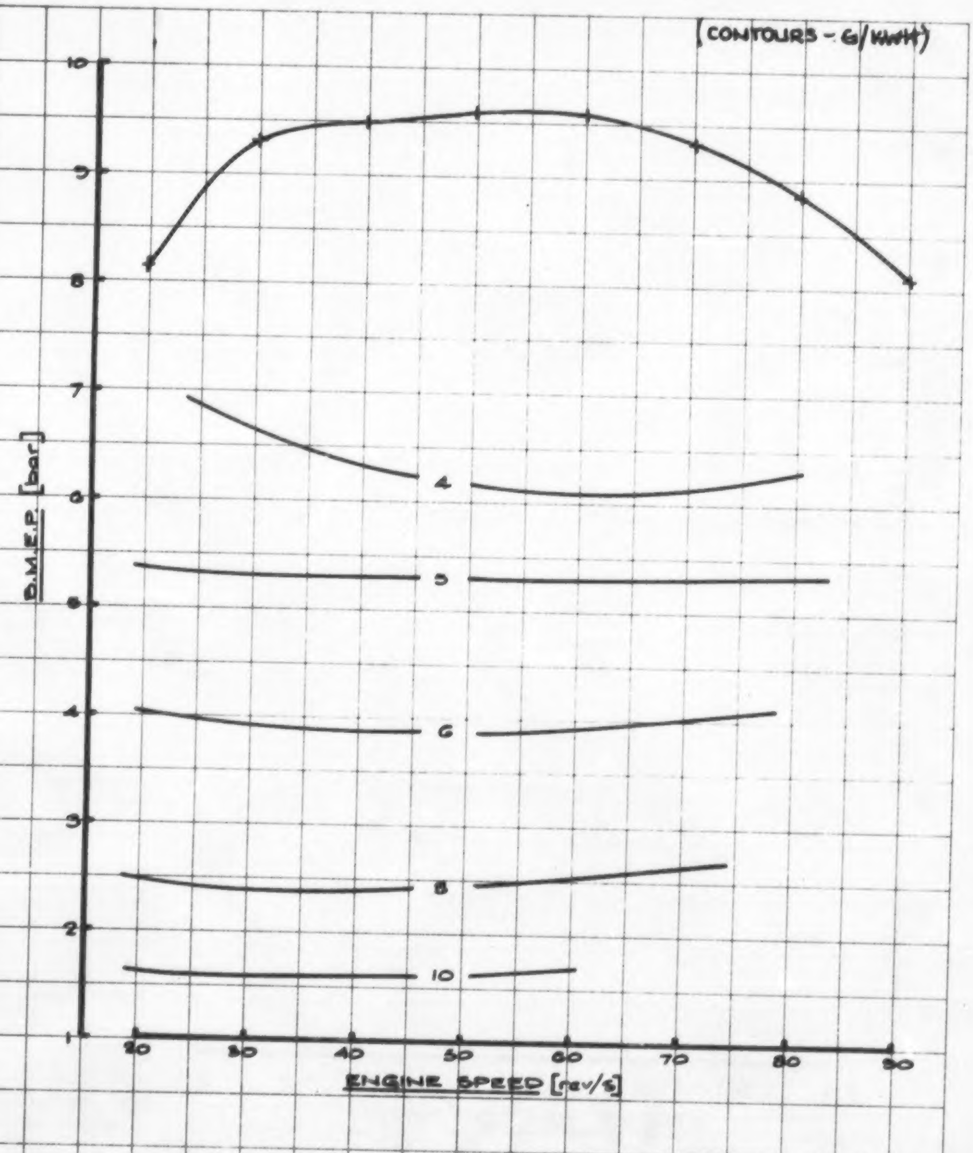
Drg. No. D 60020

Date MARCH '85

EPA 1·6L HRCC ENGINE

CO EMISSION CONTOURS - FINAL BUILD

[AUTO FUELLING, AUTO IGNITION, AUTO E.G.R.]



W M LTD 2317

RICARDO

IM.D.

FIG. No. 82

Drg. No. D 50048

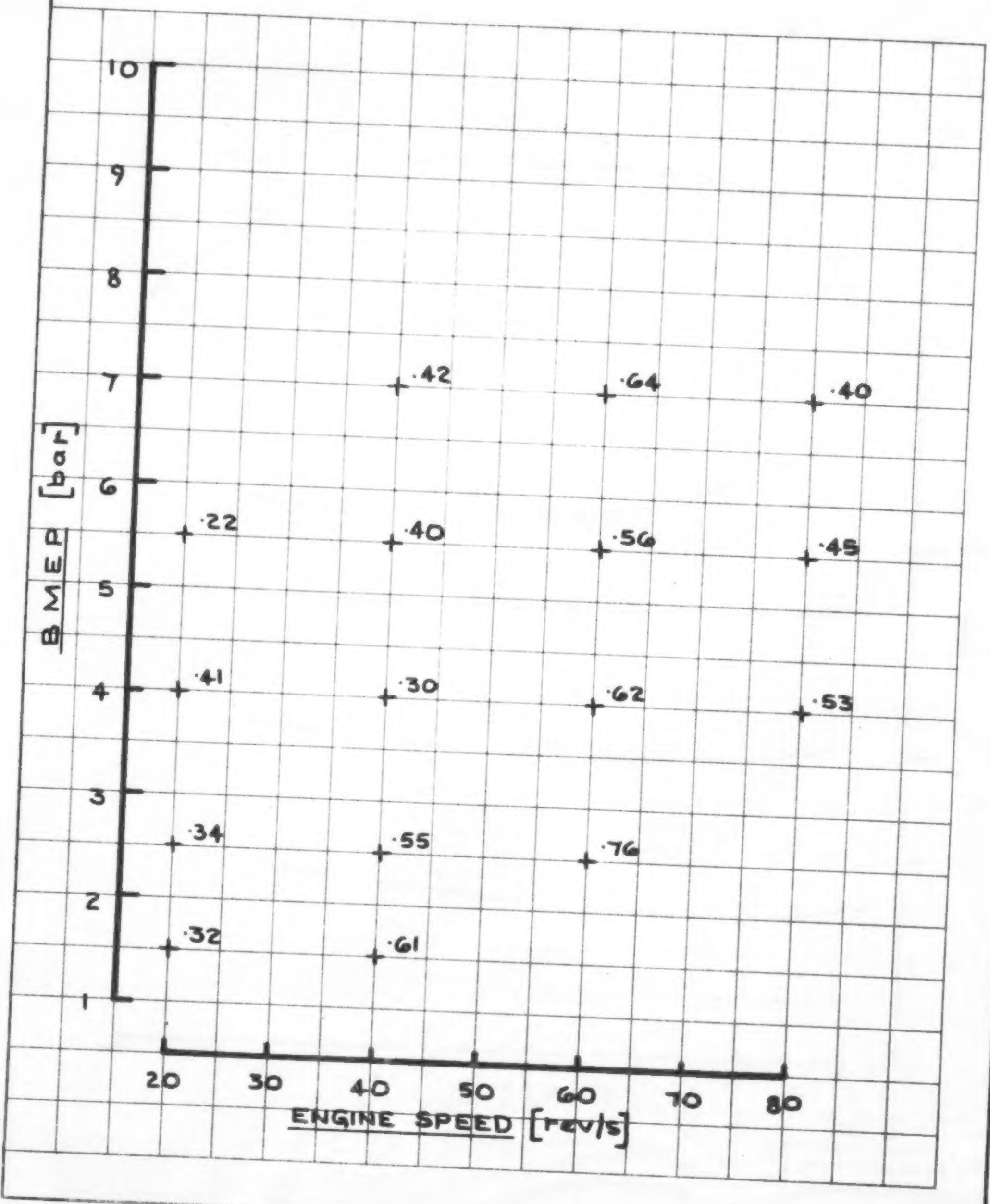
Date Feb '83

EPA 1·5ℓ HRCC ENGINE

ALDEHYDE EMISSIONS [g/kWh]

(AUTO FUELLING IGNITION AND EGR)

METHANOL FUEL.



W M LTD 2317